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AN

Elementary Manual for Students

BY

A. H. CHURCH

M.A. OXON., F.C.S., F.I.C.

PROFESSOR OF CHEMISTRY IN THE ROYAL ACADEMY OF ARTS, LONDON

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CHAPTER I.

COLOUR A SENSATION—CONNECTION OF PHYSIOLOGY AND OPTICS WITH COLOUR—LUMINOUS BODIES—ILLUMINATED BODIES—THE UNDULATORY THEORY OF LIGHT—EMISSION, REFLECTION, TRANSMISSION, ABSORPTION, REFRACTION, DISPERSION OF LIGHT.

§ 1. CERTAIN waves or vibrations which affect the fibres or rods of the optic nerve of the eye are translated by the brain into colour. Such excitation of the optic nerve may be brought about by pressure on the eye-ball, by an electric discharge, by internal causes, and, pre-eminently and generally, by light. Colour is, in fact, an internal sensation, and has no external and objective existence. As, however, it originates, in all the cases considered in the present volume, in the impact, on the optic nerve, of that force or energy or "mode of motion," which we call light, the study of some of the elementary facts of optical science may very suitably precede the consideration of the laws of colour and their applications.

§ 2. Everything that we can see is visible because it is either luminous or illuminated. In other words, visible objects are seen because they either emit light or reflect light. Examples of luminous bodies are afforded by a candle-flame, a glowing piece of charcoal, the sun. From these sources of light luminous rays are sent out; these rays are the lines along which the light is propagated. The term *beam* of light is usually applied to a large group of such rays, the term *pencil* designating a

smaller group—in both cases the constituent rays being parallel to each other. From such luminous bodies as are near the eye the rays emitted are divergent: those rays which reach the eye from the sun and other distant bright objects may be regarded as practically parallel. Divergent rays passing through a bi-convex lens emerge parallel; conversely, parallel rays transmitted through such a lens are rendered convergent; the point at which they meet is the principal focus of the lens. The forms of highly luminous bodies can be clearly seen only when much of the light which they emit is cut off by a special contrivance, such as is afforded by a piece of dark green glass or of "smoked" glass. In this way it is quite easy to see the shape and to watch the changes of the carbon-pencils in the electric arc lamp, intense and dazzling as is its light.

§ 3. The light emitted from bodies travels in straight lines, and causes, when obstructed by opaque materials, the production of shadows. The form and sharpness of shadows is influenced not only by the shape and by the relative size of the opaque body which casts the shadow, but by the form and by the degree of luminosity of the luminous body, the light of which is intercepted. Thus a brilliant luminous point gives a sharply-defined shadow, while a large luminous surface, on the other hand, produces a shadow which is surrounded by a paler and less definite one, which goes by the name of a penumbra. If we place an opaque screen, A, midway between a small source of light and a second screen, B, it will be found that the light falling on screen A will produce a shadow four times the area of A upon the screen B. This experiment likewise illustrates the law of the intensity of light at different distances from its source. The light which falls on A has to cover at double the distance (at B) four times the area, and consequently has no more than one-fourth the intensity, or, in other words, the intensity of light varies inversely as the square of the distance from the luminous point or source.

§ 4. So far we have spoken of self-luminous bodies; something must now be said of illuminated bodies. They shine by borrowed light. They are marked out and distinguished from one another by the different amounts and qualities of the light which they reflect, and also, as we shall presently see, by the manner in which they reflect it. A piece of black cloth on a white earthenware plate reflects but a very small proportion of the light which falls upon it; the plate, on the contrary, reflects a very large proportion. Had the black cloth possessed no power whatever of reflecting light, it would have been invisible; black velvet, which reflects less light even than black cloth, sometimes produces on the eye the effect of absolute blackness—that is, of an empty and dark space. Similarly, a sheet of perfectly clean and perfectly polished plate glass may appear lustrous and visible enough if the light which falls upon it is sent back to the eye; but if we are so placed in front of the glass that the regularly-reflected rays of light escape us, it ceases to be visible, and we may, perchance, stretch out our hand to take something from behind the glass, wholly unconscious of its presence. But it is possible to render a piece of polished and transparent colourless glass permanently visible. Crush it to powder, and then, in whatever direction the light falls upon its particles, the surfaces of those particles will turn back or reflect some of the light-rays, and so render the particles visible; the clear glass has become in a measure opaque. Thus, too, transparent water, when broken up into numerous fine particles, as in a cloud, has acquired, with its opacity, the property of irregularly reflecting light. A dense cloud, which appears nearly black when between the observer's eye and the sun, owing to the considerable degree of completeness with which it intercepts the light, may become brilliantly white when the sun's rays fall upon its constituent particles, for the light which cannot get through the cloud is continually reflected to and from the surfaces of its minute parts, and so illuminates

it. Thus it happens that the lower part of a cloud seen against a background of dark mountain may appear white, while the upper part of the same cloud seen against a luminous sky may appear a dull grey. The lessening of reflection, on the other hand, diminishes visibility. The numerous small reflections which occur from and between the surfaces of the felted fibres in a piece of white paper may be greatly lessened by wetting or oiling the paper, when it becomes less opaque, and at the same time greyer and clearer; to this cause the translucency of tracing-paper and tracing-cloth is due.

§ 5. We said before that illuminated bodies differ, not only in the amount, but in the quality of the light which they reflect. Now, one of the chief differences as to quality of light is its difference in colour. Powdered vermilion reflects to the eye a good deal of the light which falls upon it; this light, however, is chiefly red light, not unmixed with light of other hues, and accompanied by no inconsiderable amount of white light. A stick of red sealing-wax (coloured by vermilion) shows in some positions a bar of white reflected light in the direction of its length, while in other positions we see only the red light reflected from the particles at its surface, and from the particles at a slight depth below that surface. Why this light happens to be red in the case of vermilion we shall discuss in another chapter; we content ourselves here with pointing out that while the reflection from a polished surface is regular, that from a rough surface is irregular, and that from a coloured surface coloured. A polished plane metallic surface affords an example of the first kind of reflection, a piece of chalk of the second; the reflection differs in kind as well as in degree. So great is the difference in effect produced by regular reflection on the one hand and irregular reflection on the other, that it may be confidently affirmed that, if an illuminated polished body could be found which was wholly incapable of irregularly reflecting any part of the light falling upon it, that body would be wholly invisible.

We may therefore say that we discern bodies by the aid of the light which they irregularly reflect or scatter; a perfectly regular reflection gives, on the contrary, an image of the source of light, not of the object illuminated. Before we further explain the peculiarities of the scattering or irregular reflection of light, the great law of reflection should be stated. It is this:—"The angle which an incident ray of light makes with a perpendicular to the reflecting surface is equal to the angle which the reflected ray makes with that perpendicular:" in other words, the angle of incidence and the angle of reflection are equal. Of course, if a ray fall perpendicularly on the reflecting surface, it is reflected back along the same path. This perpendicular is called the "normal," and from it, and not from the plane of the reflecting surface, angles of reflection are measured. It should be added that both the incident and the reflected rays are in the same plane, which is perpendicular to the reflecting surface.

§ 6. Now it might be imagined that, in cases of irregular or scattered reflection, the law just stated of equal angles could hardly be applicable. But in reality, when the rays of parallel light from the sun strike upon a rough, that is, an unpolished surface, say of a piece of white paper, they are incident at all imaginable angles with the minute surfaces of the hollows and ridges which make up the reflecting substance, and such of them as are reflected obey the law, but are reflected in a countless number of different directions.

§ 7. The study of the irregular reflection of light shown by clouds and vapours and dust leads to a very important conclusion. A beam or pencil of light traversing a perfectly clear medium, whether a vacuum, or a colourless gas like air, or a colourless liquid, is itself invisible. The sunbeam, passing through a hole in a shutter into an otherwise dark room, reveals itself only when motes and dust are suspended in the air. A beam of light from the electric lamp is not seen as it traverses

True

pure water in a jar. Light is invisible: such is the conclusion to which we are forced by countless experiments and observations; but it may become at any moment visible by the interposition in its path of particles which can irregularly reflect it. Particles of dust, particles of water, particles of smoke, reveal the invisible light, not, strictly speaking, by making it visible, but by becoming visible themselves in its path. So in liquids as in air, suspended particles reveal the path of the passing rays. By adding a solution in alcohol of mastic, or a few drops of milk, or a little sodium thiosulphate solution followed by some hydrochloric acid, to a vessel of clear water through which a beam of light is passing, the invisible rays are revealed by the "scattering" which they suffer when they impinge upon the minute particles of suspended matter in the water.

§ 8. Perhaps the question may now be asked, "What is light?—what is the nature of the rays which are emitted by self-luminous bodies, and reflected by those which are illuminated?" The most reasonable answer which can be given involves a very large assumption. But we are warranted in assuming, at least provisionally, the truth of a theory which serves to explain all the diverse and complex phenomena of light, even if that theory demands some admissions which are hard to make and difficult to apprehend. The theory in question is called the Wave Theory, or the Undulatory Theory of Light. It involves two primary assumptions: namely, a motion and a something moved. What is the kind of motion, and what is moved? or rather, in what medium does the motion occur? The undulatory theory of light assumes the existence, throughout all space and throughout all matter, of an almost infinitely thin and elastic medium, called the luminiferous or light-bearing ether. It must be supposed that this ether is everywhere, universally present, without break in its continuity, in solids, liquids, and gases, and not to be excluded even from a vacuum. It cannot be material in the exact sense in which we

Shown by Kelvin to be untenable.

apply that term to the elements of the chemist, but to account for some of the phenomena of light we are compelled to endow the medium which conveys it with some at least of the properties of matter. But our older notions of the nature of the elements have been so shaken by recent researches, that some physicists have hazarded the suggestion that matter itself may be nothing more than vortices in this ether! Whatever the ether may be, the movement of this ether (or rather, a particular kind of movement in this ether) is light. This movement is in waves, the undulations of the particles of the ether being *across* the direction in which the light is propagated. Ordinary light consists, then, of vibrations in all azimuths, but all *perpendicular* to the path of the ray, and is supposed to originate in the following manner:—The particles or molecules of a luminous body are in a state of disturbance, a state of intensely rapid motion. This motion of the molecules is communicated to the ether, and sets it in vibration, and is propagated in all directions in the form of spherical waves. Reaching the retina of the eye, this fine motion of the ether is translated by the brain into the sensation which we call light. This is a broad and general statement, for, as we shall explain more fully further on, not all the vibrations set up in the ether by luminous bodies are thus capable of translation into light. For the waves of the ether are of different lengths, and it is only those which measure from about $\frac{1}{33000}$ of an inch, on the one hand, to about $\frac{1}{65000}$ of an inch, on the other hand, which are capable of exciting the sense of sight. Or, indicating these wave-lengths by their duration in time, the visible waves vary between the $\frac{1}{390}$ and $\frac{1}{770}$ of a billionth of a second. The longest and slowest of these waves gives the sensation of red, the shortest and quickest that of violet. Longer waves than the longest above-mentioned do not excite vision, but are manifested as heat; shorter waves than the shortest above-mentioned do not excite vision, but cause chemical change, and are known as actinic. The relations of heat,

light, and actinism to each other will be discussed in Chapters II. and III., at least so far as they are connected with the primary subject of the present volume, namely, the nature and causes of colour.

§ 9. Thus far we have considered—very briefly, it is true—the emission and the reflection of light, as well as the undulatory theory. A few words must now be said as to the meaning of the terms transmission, absorption, refraction, and dispersion of light. Bodies are said to be *transparent* when they permit light to pass so freely as to allow objects to be perfectly discerned through them; *translucent*, when they allow light to pass less perfectly, so that objects on the other side of them cannot be clearly distinguished; *opaque*, when the light is wholly shut off. But, in point of fact, no bodies are perfectly transparent or perfectly opaque. The most colourless and flawless polished glass cuts off some rays, while some substances, such as metals, which are commonly regarded as quite opaque, become transparent, or at least translucent, when reduced to a state of great tenuity in the form of thin leaves. Thus, the sun may be conveniently viewed through a plate of glass which has been coated on one side with a thin film of pure silver, the light which passes through the metal appearing of a blue colour, while the light transmitted through a piece of gold-leaf is bluish-green.

§ 10. In addition to this, it may be remarked that different transparent bodies, which appear to allow light to pass through them with equal and perfect facility, do, in reality, arrest the passage of some of the constituent rays, if only the transmitted pencil of light be critically examined by appropriate optical methods. Take the case of water. A pencil of white light, made up, we will assume, of 1,000 rays, perpendicularly strikes the surface of some water two or three inches deep, and contained in a suitable vessel; eighteen rays will then be reflected towards the original luminous source, while 982 will find their way through the water unchanged. But increase

the thickness of the layer of water to something like two feet, and this free transmission will no longer occur. The number of the emergent rays will be distinctly reduced, and their quality will be altered in one respect: that of colour. The eye will perceive that they are bluish, not white, the explanation lying in this fact, that all the constituent elements of white light have not been equally transmitted through the thick layer of water, some of the colour-producing waves being quenched or absorbed, leaving a large residuum which passes but which shows in its bluish hue the suppression that has taken place. The same phenomenon, in a much more obvious form, is observed in the case of coloured liquids, such, for instance, as an aqueous solution of sulphindigotic acid or of carminate of ammonia. In the former case a considerable proportion of the large waves of red light is suppressed, the transmitted rays being chiefly blue, while in the latter case the transmitted waves are those which produce the sensation of red, the intercepted those giving green and blue. Still the production of colour is not always the result of the imperfect transmission of light through a so-called transparent medium. For instance, there are several apparently colourless liquids, such as alcohol, benzene, and an aqueous solution of didymium salts, in which the imperfect transmission of certain light-waves is so distributed amongst them as not to affect the hue of the transmitted beam, although it lessens its intensity. How this occurs will be explained further on (see Chapter II.).

§ 11. In the preceding paragraph we have given some examples of the absorption of light, the liquids mentioned "filtering" the rays, permitting some to pass and "straining off" others, colour being in very many cases the result. Solids, such as coloured glass and coloured gems, constantly produce similar results. One example will suffice to illustrate this point. We will take the case of the very beautiful mineral known as lapis-lazuli, from which the pigment genuine ultramarine is prepared. A

very thin slice of lapis-lazuli appears transparent under the microscope. White light cannot be transmitted in its entirety through it. The white light does not *become* blue by traversing the lapis, but is decomposed in its passage, a very large number of its constituent vibrations being in some way intercepted, quenched, or absorbed, while the remainder, which escape absorption, on their emergence produce the sensation which we call blue; this is a case common enough of selective absorption. Let us proceed a step further. If we reduce the lapis to an impalpably fine powder, it remains blue, but becomes apparently opaque. In reality, however, it retains a certain degree of translucency. White light falling upon this powder is in part reflected unchanged, but a portion plunges into the surface particles and suffers the absorption of its longer red and green waves, while the residue emerges as blue light, and is irregularly reflected from the general surface of the powder. Such selective absorption is the main cause of the colour of pigments.

§ 12. It has been stated before that when a beam of white light falls perpendicularly upon the surface of water more than 98 per cent. of the rays pursue a straight course through the water, the direction of the beam being unaffected by its passage from the rarer medium, air, into the denser medium, water. But the result is altogether different when the incidence of the beam is oblique. Not only is a much larger proportion of the incident light reflected from the surface of the water, but the rays which penetrate that medium are bent down towards the perpendicular, or, as this change of direction is called, refracted. The more oblique the incidence of the beam, that is, the larger the angle it makes with the perpendicular, the more strongly is it refracted. However, whatever the angle, refraction always obeys what is known as the "law of sines," the sine of the angle of incidence of the beam in air bearing to the sine of the angle of refraction in water the invariable ratio of 4 : 3. Expressed as a decimal fraction

this ratio, which is identical for all angles, becomes 1·335, which value is called the "refractive index" for water—air being assumed in this, as in all cases not specially excepted, to have a refractive index of 1. A familiar example of refraction is the case of a stick partially immersed in a vessel of water, which appears broken at the surface of immersion when placed obliquely. But it may reasonably be asked, "How is it, if refraction in a denser medium is *towards* the perpendicular, or *downwards*, that the immersed part of a stick seems to be bent upwards?" It is because the rays from the immersed portion of the stick, before they reach the eye, have to pass from the denser medium of the water to the rarer medium of air, and in consequence, the effect of the previously described refraction is precisely reversed. Another familiar instance of refraction is afforded by placing a coin in an opaque bowl, so that it cannot be seen by an eye above and to the side of the edge of the vessel: on pouring water into the vessel, the image of the coin becomes, as it were, lifted up into view by refraction. The explanation of refraction on the undulatory theory involves the conception of a certain degree of hindering in the motions of the ether by the denser medium. One side of the wave-front of a beam of light striking obliquely the surface of water, must meet that surface before the other side, and must be first hindered or retarded by it. The beam swings round, the other side reaches the denser medium, and then the whole beam proceeds on its path but more slowly and in a new direction.

§ 13. We are now in a position to consider the mode of action on light of the most important of all optical contrivances for studying the nature of light and of colour: that is, the prism. We know that a beam of light in passing from air into water, or glass, or other relatively dense medium, is refracted towards the perpendicular; conversely, in passing out of glass or water into air, the reverse refraction occurs, and to a precisely equal extent. If, therefore, a beam of light enters

obliquely a piece of glass, the faces of which are parallel, the refraction towards the perpendicular on entering the glass will be exactly compensated by the refraction away from the perpendicular on leaving the second parallel surface of the glass, so that the emergent beam will necessarily be parallel with the incident beam, though not continuous therewith, for it has been deflected in the glass. But suppose we employ a prism of glass instead of a flat plate, then the beam is permanently refracted on emergence. The prism, so extensively employed in optical experiments, is a wedge-shaped piece of some

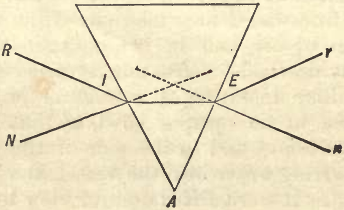


Fig. 1.

transparent and colourless substance, generally of flint glass, but sometimes of other kinds of glass, or even quartz or other transparent minerals: it is an indispensable instrument in the study of colour. The angle enclosed by two oblique sides of this prism is called the refracting angle. If we place the prism so that this angle, A (Fig. 1), is below, and the opposite side of the prism horizontal, then a beam of light, R, from above falling on to one of the oblique sides, I, will be refracted *towards* the perpendicular or normal, N, of that side in passing from air through the glass, and on emerging into air from the second surface, E, will be again deflected, but this time in the opposite direction, namely, *from* the perpendicular or normal, *n*, to that surface, and therefore in an upward direction, *r*. The new direction of the emergent beam will deviate from the original direction

in degree according to (1) the density of the glass, (2) the angle made by the oblique sides of the prism, (3) the position of the prism. The last factor in the amount of deflection is of much importance in working with the prism, and it is always desirable to secure such a position for it that the incident and emergent rays make equal angles with their respective surfaces; this is known as the position of minimum deviation. It should be added here that for many purposes hollow prisms may be substituted for those of one material; they are generally filled with carbon disulphide, Sonstadt's solution of potassio-iodide of mercury, or some other liquid having a higher refractive index than that of flint glass.

§ 14. Commonly something more happens to the beam of light which has traversed, as just described, the prism than a mere deflection. If the light be simple, if its waves be of one measure only, it will be simply deflected; if, as is nearly always the case, the light be compound, if its waves be of different lengths, then they will be differently affected by the prism. It will retard the short waves more than the long ones, and so we shall find that these short waves are more refracted. The more refrangible rays are, then, the short violet rays, the less refrangible rays are the longer red rays. In every case, then, where a luminous body emits rays of various degrees of refrangibility, these rays can be separated from each other by means of the prism. As solar light consists of an enormous number of rays having different refrangibilities (in consequence of their differing wave-lengths), it may be decomposed, analysed, or split up into an enormous number of rays, the wave-length of each of which belongs to a particular component. Not all these different vibrations can excite vision and the sense of colour, as we have already learnt, but the heat-rays, whose vibrations are even longer than those of the red rays, as well as the actinic rays, whose vibrations are still shorter than those of the violet rays, obey the same law as the visible rays. It must not, however, be

forgotten that the material of the prism, though practically transparent to true light-rays, is generally very far from being equally transparent, or "dia-actinic," to the chemical rays, or dia-thermic to the heat-rays.

§ 15. When sunlight is examined by means of the prism, it will be found, if the necessary care be taken to insure a pure and long spectrum, or ordered sequence of differently refracted rays, that there are gaps in its continuity—that there are blank spaces to which no ray corresponds. The light of the electric arc, on the other hand, when analysed by the prism, presents no such breaks, consisting as it does of an unbroken series of rays having every possible wave-length within its range. Most burning metals and glowing vapours emit fewer rays, so that their light, however intense, is of much simpler constitution than that of the electric arc or of the sun, being made up in some cases of very few elements, a red ray in the case of lithium being, for example, followed at a certain interval by an orange ray, then by one of a blue colour, and finally by a violet one. In other words, the light of burning lithium (at the temperature of the electric arc) is made up of four rays having different wave-lengths, and therefore different refrangibilities. Consequently the prism, in refracting these rays differently, separates or *disperses* them widely, and enables us to observe them apart from each other. Such dispersion is, then, the general accompaniment of the refraction of compound light, although it does not always happen that substances having the highest refractive index possess also the highest power of dispersion.

CHAPTER II.

COMPOSITION AND ANALYSIS OF LIGHT — THE SOLAR SPECTRUM—DIFFERENT COLOURS DIFFERENTLY REFRACTED—WHITE LIGHT ALWAYS COMPOUND, COLOURED LIGHT OFTEN SIMPLE—RE-COMPOSITION OF WHITE LIGHT — THE RAINBOW — SOUND AND LIGHT COMPARED AND CONTRASTED.

§ 16. THE compound nature of the sun's light was first demonstrated by Kepler, and a century and a half later was more thoroughly investigated by Sir Isaac Newton. His primary experiment may be easily repeated, and a beam of the solar rays analysed into its

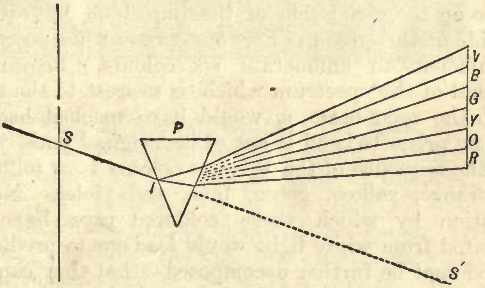


Fig. 2.

constituent parts. The arrangement shown in Fig. 2 may be adopted. Through a small circular hole, or, preferably, a narrow slit in the shutter of a darkened room, allow a beam of sunlight, S, to fall obliquely upon the face, I, of a glass prism, so arranged that its base, P, is uppermost and horizontal. The beam will be refracted and dispersed, as described already in §§ 13 and 14. If the prism have a refracting angle of about 60°, a vertical

band of rainbow colours will be produced, and may be examined on a screen of white card-board placed at a distance of five yards or so from the prism. This band is the solar spectrum. It consists of a very large number of different hues, amongst which we at first single out three as the most conspicuous: namely, red, green, and blue-violet. Looking a little more closely at this coloured band, we find no difficulty in adding orange, greenish-yellow, greenish-blue, and violet to the list. A pure yellow can hardly be recognised, for this hue occupies an exceedingly narrow space in the spectrum of sunlight. Nothing at all approaching the hue of indigo can be discerned, although, from the time of Newton onwards, the name indigo has been generally applied to the coloured light which separates the blue from the violet. But as the pigment indigo in its purest state is a dull blue having a greenish cast, its place in the spectrum would certainly not be on the violet side of the pure blue, but rather on the side of the green. For our present purpose it will be sufficient to enumerate six colours. Beginning at that end of the spectrum which is nearest to the spot S′, which the solar beam, S, would have reached had there been no prism to bend it out of its original path, we find that the sequence of the spectral colours is as follows:—red, orange, yellow, green, blue, and violet. Now the operation by which these coloured rays have been separated from white light would lead one to predict that they cannot be further decomposed—that they cannot be themselves amenable to prismatic analysis, or be separated into other kinds of colour. This anticipation is realised by actual trial. For if, as is shown in Fig. 3, one of the colours, *v*, of the spectrum be allowed to pass through a hole in the screen, E, on which the band of coloured light was first received, it will be found to remain unaltered after having been transmitted through a second prism, B. The ray will be refracted, of course, but it will remain violet, as seen on screen H.

§ 17. The celebrated chemist Wollaston first described,

in 1802, the existence of gaps represented by dark lines in the spectrum of the sun. Twelve years afterwards Fraunhofer further investigated this point, and mapped out no less than 576 of these dark lines, assigning to the most prominent amongst them the letters of the alphabet. These lines, or vacant spaces, in the solar spectrum have been traced to the absorptive power for certain rays possessed by the gaseous envelopes which surround the incandescent body of the sun. From our present point of view they are of chief interest to us as furnishing a ready means of fixing and identifying the variously

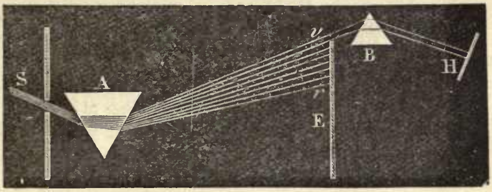
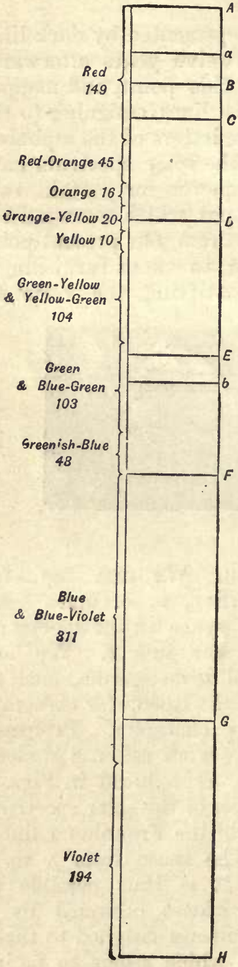


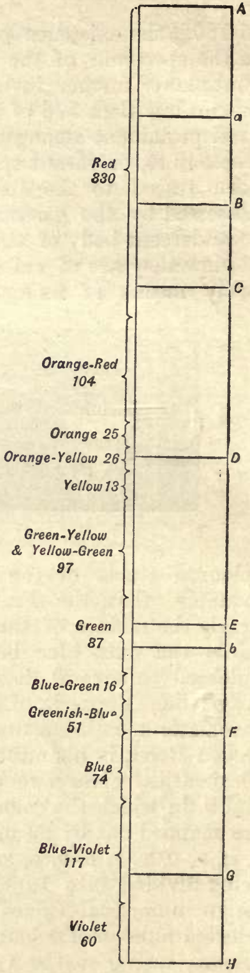
Fig. 3.

coloured tracts of the spectrum. We may say, for example, that the Fraunhofer line, D, occupies very nearly the middle of the orange space in the spectrum, while the pure blue begins at the line F. We are indebted to several distinguished investigators, such as Angström, Vierordt, Listing, and Rood, for elaborate chromatic measurements of this character. Professor Ogden Rood, in his most valuable work called "Modern Chromatics," gives two diagrams, reproduced in Figs. 4 and 5, in which the coloured spaces of the solar spectrum are mapped out by means of ten of the Fraunhofer lines, A, *a*, B, C, D, E, *b*, F, G, and H. The space from A to F being divided into 1,000 parts, it is thus possible to assign numerical values to the spaces occupied by a selected number of colours. The names assigned to these colours, owing to the vagueness which seems to be inherent in such a nomenclature, may lack precision, but



A
a
Red
149
B
C
Red-Orange 45
Orange 16
Orange-Yellow 20
D
Yellow 10
Green-Yellow
& Yellow-Green
104
E
Green
& Blue-Green
103
b
Greenish-Blue
48
F
Blue
& Blue-Violet
311
G
Violet
194
H

Fig. 4.



A
a
Red
330
B
C
Orange-Red
104
Orange 25
Orange-Yellow 26
D
Yellow 13
Green-Yellow
& Yellow-Green
97
E
Green
87
b
Blue-Green 16
Greenish-Blue
51
F
Blue
74
Blue-Violet
117
G
Violet
60
H

Fig. 5.

it is so easy for any one studying the subject of colour to examine for himself the actual appearances presented by the spectrum that the uncertainty of colour-names is here of little moment. The two figures we give differ, it will be observed, in one important particular, namely, the relative spaces occupied by the several hues. This difference is due to the different means employed to produce the two spectra represented. Fig. 4 represents a spectrum obtained by the use of a flint-glass prism, while Fig. 5 was drawn from a spectrum obtained by the employment of what is called a "diffraction grating," that is, a plate of glass silvered on the back, and having ruled on the front an immense number (nearly 19,000 to the inch) of very fine parallel equi-distant lines. This plate, ruled by Rutherford, gave to Professor Rood, whose results we here produce, a magnificent spectrum of great length and remarkable purity. This spectrum may be regarded as normal, for in it the colours between the red and the yellow are not crowded together more than the differences in their respective wave-lengths warrant, as is the case with the ordinary spectrum obtained by the use of a prism, owing to the unequal dispersive power of glass for different rays. Another difference between the two spectra seems at first sight to be more serious. The luminosity of the different parts of the two spectra is differently distributed, and consequently, as is pointed out in § 119, the hue of corresponding parts will not be identical; for a very luminous red tends towards orange, and a very dull blue towards violet. It should be added here that a part only of the visible spectrum is represented in Figs. 4 and 5, for a dull red verging on brown or chocolate may be detected beyond the line A, while a dull lavender-grey extends beyond the line H at the violet end.

§ 18. We have seen that the white light of the sun is compounded of an almost innumerable series of coloured elements, a large number of which can be separately examined by covering up all the rest of the

spectrum, and viewing the selected portions individually through a narrow slit. All white light from other sources will be found to be compound, although there are many cases in which not more than three, or even two, colours can be separated from it. Coloured light, on the other hand, may often be simple, not admitting of analysis into rays having different wave-lengths; such is the nature of every one of the coloured lights of the spectrum. But coloured lights may be, and often are, compound, sometimes consisting of two, and often of many more differently-coloured elements, although the eye recognises but a single colour in the complex ray. A striking instance is afforded by yellow. There is an elementary yellow in the solar spectrum lying on the green or more refrangible side of the line D. By no contrivance can we optically decompose this spectral yellow, to which belongs a definite wave-length. But there are many compound yellow lights—lights which give us, as the sum of the simultaneous visual impression of their several components, a sensation of yellow not to be distinguished by the brain from the simple yellow of the spectrum. Such a compound yellow may be formed by throwing on the same portion of a screen a part of the red light and a part of the green light of a pure spectrum. Similarly there is a pure and simple blue in the spectrum, but a blue indistinguishable from this in hue may be obtained by mingling green and violet light.

§ 19. It follows, from what has been advanced in this chapter, that white light admits of re-composition by the re-union of its separated constituents. Divide a solar spectrum obtained with a slit and a prism into two parts, equal or unequal, by mirrors or lenses, and throw the light from each part on to the same spot on a screen: a *white* image of the slit will be the result. Similarly reflect, by means of a set of mirrors, the separated red, orange, green-blue, green, blue, blue-violet, and violet rays of a spectrum on to the same spot, and white light

will be re-formed: the apparatus is shown in Fig. 6. Or again, we may by a second prism, in a reversed position, re-join the colours separated by a first prism, and exactly undo its effect, again producing white. If a space be left between the contiguous sides of the two prisms, a black card may be inserted more or less

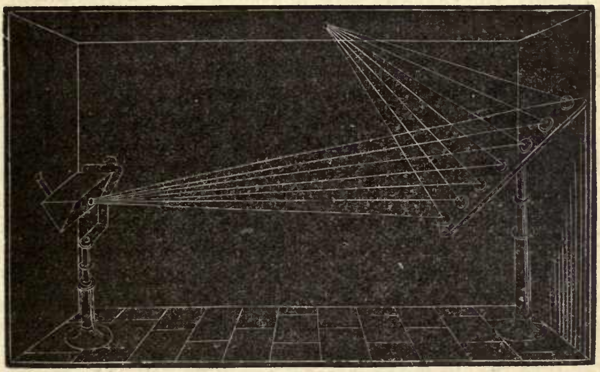


Fig. 6.

deeply between them, and we may thus cut off a part of the rays separated by prism number one—then the light emerging from the second prism will have been deprived of some of its coloured elements, and will no longer be white. Fig. 7 illustrates the arrangement of the prisms and the path of the beam,

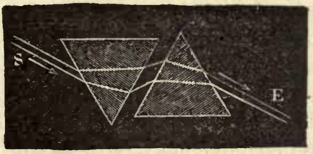


Fig. 7.

s, as it enters the first prism, and as it leaves the second prism as the re-constituted white beam, E.

§ 20. Another mode of re-uniting colours so as to form white was suggested by Newton. A disc (Fig. 8), so mounted upon a multiplying wheel as to admit of

rapid rotation, is painted in radial sectors with such opaque pigments as afford the nearest approximations to the principal colours of the spectrum. It is not necessary to employ a large number of pigments; three, indeed, will suffice, namely, scarlet-vermilion, emerald-green, and ultramarine-blue (the last having been mixed with a little zinc-white). The surface occupied by the vermilion should be about one-sixth larger than that painted with the artificial ultramarine; the emerald-green must occupy an area intermediate in size between that of the red and that of the blue—the exact proportions have to be determined by experiment for the particular specimens of pigments employed. It is a good plan to repeat this triple group of coloured sectors three or four times on the disc. If a larger number of colours be employed, including orange, yellow, blue-green, and violet, the same final result will be obtained when, on rapidly rotating the disc, the successive impressions of the coloured sectors are mingled on the retina of the eye. A perfect white is not indeed produced, because all the coloured sectors combined, being severally *parts* only of whiteness, must present a total luminosity much less than that of a white disc. Thus, six coloured sectors cannot offer more light to the eye than a small fraction of that furnished by a white disc of corresponding size. We must be satisfied with a neutral grey, a mixture of white and black, for even a white disc with a low illumination appears grey. When, too, we remember that a very small proportion of the light falling upon such a coloured disc is reflected from its surface, the dulness of the re-

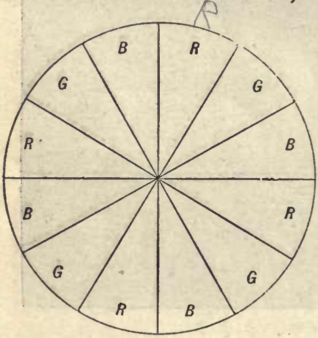


Fig. 8.

sultant white must not surprise us. Indeed, the degree of absorption (of parts of the white light) which produces colour in pigments is so great that, with the three pigments named above, it amounts to a commixture of $71\frac{1}{2}$ parts of black with $28\frac{1}{2}$ parts of white. In other words, the grey produced by the rotation of such red, green, and blue sectors may be imitated by rotating a disc painted with sectors of black and white, in the proportion of $71\frac{1}{2}$ per cent. of the area with the former, and $28\frac{1}{2}$ per cent. with the latter. In practice it is usual to construct Newton's disc by means of sectors of coloured paper.

§ 21. A form of rotating disc for the re-composition of white light makes use of transmitted instead of reflected colours. Various transparent pigments mixed with varnish or sectors of coloured gelatines are applied to a disc of glass. White light transmitted through this parti-coloured disc becomes variously coloured by absorption as it passes through the transparent pigments, and so long as the disc is allowed to revolve slowly no unusual phenomenon is observed. But on rapidly rotating the disc by any suitable mechanical contrivance, the colours, when a sufficient speed is attained, are mingled on the retina, the coloured images being superposed owing to the persistence of visual impressions, and a neutral whitish-grey is the result. There is still another apparatus for re-combining colours into white; it is known as Maxwell's colour-top, but this is nothing more than a greatly improved and most ingenious form of Newton's disc. We shall have frequent occasion to refer to this arrangement in succeeding chapters, and to bring forward some of the instructive results as to the mutual relations of colours which may be obtained by its use.

§ 22. It should be noted that, in all the above-described arrangements for re-combining coloured into white light, it is necessary to use sunlight or other practically white light, or else to modify the proportions of the coloured sectors in accordance with the different hue of the

tinted light employed. For instance, most of the parti-coloured discs, prepared as described in the present paragraph, even if their coloured sectors are so adjusted as to give a good neutral grey by daylight, produce a decidedly reddish-grey by gas or candle-light, although by the electric arc light, and by the light of burning magnesium, the desired result is satisfactorily obtained. To use them with a "warm" and orange-hued artificial light, either of two plans may be adopted: increase the amount of blue-green in the disc, or interpose between the eye and the disc a piece of pale blue-green glass or coloured gelatine; the hue required is very nearly that of the paint known as "viridian," or "emerald oxide of chromium."

§ 23. The grandest natural example of the decomposition of white light into its coloured constituents is furnished by the solar rainbow. The parallel rays of sunlight, falling at certain angles upon the nearly spherical rain-drops, are refracted and reflected within them, and emerge as coloured rays. The gatherings of these separated and nearly parallel rays, in the order of their several refrangibilities, into groups of differently-coloured beams, constitute the bands of the primary bow; the fainter secondary bow is produced from other solar rays, which suffer not only two internal refractions, and one total internal reflection within the drops, but a second internal reflection, which weakens the brilliancy of the coloured bands, and reverses their sequence.

§ 24. Endeavours have often been made to draw analogies between the sensations of sound and those of colour. Such apparent relationships as have been pointed out are for the most part quite fanciful. The nature of sound-vibrations differs from that of light-vibrations in many important particulars, notably in this point: that while sonorous waves move *in* the direction of their path, the motions of light-waves are transverse. Nor is there any definite ratio between typical colour intervals and the musical intervals of the octave. Thus,

in the case of pairs of our complementary colours, the relation of wave-length which subsists between them is not uniform, but varies considerably; with some pairs it may be expressed numerically as 1 : 1·2, with others it is 1 : 1·333, or, adopting musical notation, the relation may be said to vary from that existing between a note and its fourth to that between a note and its diminished third. Again, the eye is more appreciative of differences in wave-length in the middle region of the spectrum than it is of differences towards either end; but the ear does not possess a corresponding peculiarity with regard to musical sounds. While we can *hear* about eleven octaves, we can *see* but one octave. The sound-waves which the human ear can recognise range from sixteen vibrations in one second of time to 38,000 in the same period; the light-waves which the human eye can perceive range between 390 millions of millions in one second to 770 millions of millions. When several notes are sounded at once we do not get a sound of medium pitch, but either a discord, or else a consonance or chord-euphony, in which the elementary tones may be distinguished. But when a number of colours, or even two or three only, strike the eye, we get a medium colour, weakened by whiteness, and not enriched by the simultaneous action of the chromatic elements upon the retina. Again, and lastly, let us compare and contrast a musical trill or shake on two notes with the successive presentation of two colours to the eye. If the number of vibrations necessary to produce an optical effect in the latter case were commensurate with those required in the case of the trill, the lapse of time needed between the two notes would have to be measured by years! In fact, colour sensations involve rather the element of space than that of time. The symbolism of colour demands a passing notice, although it scarcely admits of serious discussion. If we allow that the obscurity and gloom associated with black may reasonably be connected also with sorrow, mourning, and death: if we accept white

as typical of purity and innocence; still we shall have some difficulty in explaining the use of green as symbolising felicity and the Resurrection, or in interpreting blue as involving the ideas of piety and divine contemplation. Readers who are curious as to this subject may be referred to the English translation of Baron P. de Portal's Essay on Symbolic Colours.

CHAPTER III.

PRODUCTION OF COLOUR BY ABSORPTION, BY DIFFRACTION, BY POLARISATION — SELECTIVE ABSORPTION AND SELECTIVE REFLECTION—PRODUCTION OF COLOUR BY LOSS OF COLOUR—HUE AFFECTED BY THICKNESS OF ABSORBENT MEDIUM—INTERFERENCE OF LIGHT-WAVES —COLOURS OF THIN FILMS.

§ 25. The absorption and reflection of light are very closely related, yet there are many coloured bodies which, instead of absorbing some of the coloured component rays of white light, and reflecting others, transmit those rays which they do not reflect. Even a third condition exists, in which a substance reflects some of the coloured component rays of the incident light, transmits others, and absorbs the remainder. And there are cases in which a further and more complicated action takes place; for some coloured substances when white light falls upon them not only reflect some of its coloured rays, transmit others, and absorb others, but also alter the refrangibility, and therefore the hue, of some at least of the rays which they allow to pass. We may now briefly discuss and explain the production of colour by these methods.

§ 26. Let us suppose a substance such as a transparent crystal of cinnabar (vermilion or mercuric sulphide) or else of cuprite (copper sub-oxide). These bodies appear

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red both by transmitted and by reflected light. Of the white light which falls upon them, these substances reflect part unchanged, part plunges to a small depth beneath the surface, and emerges as a reflected beam with a red hue, having lost the other coloured constituent rays by absorption, and the remainder, in passing through the substance, suffers a similar selective absorption, and emerges as a transmitted beam of red light. In many such cases, however, the reflected red and the transmitted red, similar as they may appear to the unaided eye, prove on analysis with the prism to be somewhat differently constituted. The next cases to be considered are those in which the coloured reflected light is entirely different from the transmitted light. A few metals may be cited, along with iron pyrites and such complex substances as magnesium platino-cyanide, potassium permanganate, murexide, indigo, eosin, magenta, quinolin-blue. The yellow colour of metallic gold is due to selective absorption. True, a plate of gold reflects some of the incident white light unchanged, but it quenches in another portion many of the green, blue, and violet rays, and so leaves the residual red, orange, and yellow to produce the warm yellow hue which is so characteristic of the light reflected from gold. It might seem likely that this metal would transmit, when in sufficiently thin leaves, all those coloured rays which it does not reflect. This is true to a great extent. If we coat a thin plate of colourless glass with mastic varnish, and, while this is still tacky, let a leaf of gold adhere to it, we find that it transmits a beautiful green light, which contains a large part of those rays which are not found in the light reflected from a surface of gold, and are entirely absorbed or quenched in a sheet of the metal too thick to be translucent. Solid indigo affords us another and similar example of selective absorption and reflection. If a lump of pure indigo be pressed with an agate burnisher, a copper-coloured streak makes its appearance. So long as the substance of the indigo is not virtually continuous—that is, so long as it

exists in the form of minute powdery particles—so long it shows no sign of a copper-coloured reflection, but appears blue. Now, the blueness thus seen by reflection is not actually produced in or by simple reflection. The incident light—or, rather, a part of it—plunges to some depth amongst the blue particles, and passes through them, a chromatic selection being thereby made, so that the light finally reflected to the eye, having been previously deprived by selective absorption of some of its coloured constituents, is blue. Increase the coherence of the blue indigo powder, either by pressure or by the process of sublimation in which crystals are formed, and then, though the transmitted light, if it can be obtained, will be blue, the reflected light will be copper-coloured. Similarly, eosin (one of the coal-tar dyes) in its solid form reflects a yellow-green light, and transmits a red, while potassium permanganate in crystals reflects a bronze light, and transmits a purple or violet. In these and in many other cases where the coloured reflected light has that peculiar intensity of lustre which approaches the metallic, the coloured rays of the reflected light, if re-united to those of the transmitted light, produce a hue which very nearly approaches white. A very curious instance of the difference in colour between the reflected and the transmitted rays is afforded by the brass-yellow crystals of that very common mineral mundic, or iron pyrites. Their lustre is metallic, and their colour as ordinarily seen is brass-yellow. As this substance, which when compact is quite opaque, is gradually reduced to very fine powder, the hue changes and deepens, until at last we have a material which might almost be termed blue—at least, we may call its colour a greyish-blue. Although this subject has not been thoroughly investigated, it would appear that the bluish colour of iron pyrites, when in impalpable powder, is due to the selective absorption exercised upon white light when transmitted through its very minute particles. The phenomena described and discussed in the foregoing

paragraph often suffice to explain the great difference in colour between a compact solid and its powder.

§ 27. We will now consider the case of such coloured bodies, whether solid or liquid, as would, in ordinary parlance, be called transparent. Of course, were they perfectly transparent to all the waves of white light they would not be coloured at all. It is because they are transparent to some only of such waves, and opaque or partially opaque to others, that the light they transmit is coloured. First of all, let it be clearly understood that white light is not converted into coloured light by passing through a coloured medium. As a general rule, it becomes coloured not by change, but by loss. Something coloured is removed from it during transmission, and a coloured residue is left. You cannot *turn* red light into green light by a piece of green glass; if the particular kind of green glass chosen is quite opaque to the red light, the latter will be invisible when the green glass is placed between the eye and the luminous source. And when white light passing through green glass yields a green beam, the result is obtained through the absorption by the green glass of the red and of all the other ray, save the green, or, at least, of all the other rays save those which, viewed together, give the sensation of green. A very easy experiment with the spectrum of any white light proves this point. We have only to provide ourselves with a few strips of differently-coloured glass, and to interpose them between the luminous source and the spectrum projected on a screen. Beginning with a red glass, we find that its interposition between the light and the red region of the spectrum does not visibly affect the colour of the latter. Passing on to the orange band, we shall find this becomes less luminous than before, and this darkening effect becomes more conspicuous as we approach the green, where, in all probability, we shall observe that the red medium very nearly destroys all the light. Similarly a blue glass cuts off little light from the violet and blue portions of the spectrum, a good deal

from the green, and nearly all from the yellow and orange portions, and considerably darkens the red. Were the blue light transmitted by the glass perfectly homogeneous —that is, did this medium transmit light of one refrangibility only, or rather, did it transmit rays the refrangibilities of which differed only so much that the colour sensations they excited in the eye could not be distinguished, then it would blacken every part of the spectrum save the blue. But no such glass exists, all blue media permitting considerable quantities of green (and often of red) rays to pass through them.

§ 28. In continuing our experiments with coloured glasses and strips of thin gelatine (used for cracker-

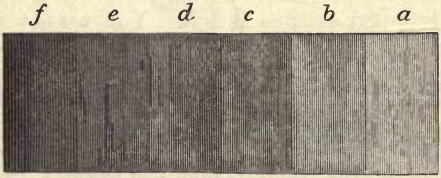

Fig. 9.

bonbons), we shall soon come across another phenomenon of great interest. We shall find that transparent-coloured media do not appear of the same colour when the thickness through which the light is transmitted is made to increase or diminish. The easiest way to try this experiment is to cut half a dozen strips of coloured gelatine, each shorter than the last by a quarter of an inch. Wet the largest piece and lay it on a sheet of colourless glass; superpose on this number two, and so on to the last and smallest strip. We might expect to find nothing more than a darker tint, a progressive purity or richness in colour, as we proceed from the single layer to the band where six layers are superposed. But this is not all that we see. We find that the hue alters as well as the richness, or comparative freedom from white. In the

case of yellow gelatine (or yellow glass), *a*, in Fig. 9, will of course show the normal hue, but *b* will not be a deeper yellow : it will be orange-yellow, while *c*, *d*, *e*, and *f* will verge gradually towards a full orange, or even a red. We learn from this experiment that the single plate not only exercises less absorbent power than two or more plates, but that the absorption differs in kind as well as in degree, the thicker layers cutting off in succession groups of variously-coloured rays which the thinnest layer permitted to pass until nothing but orange-red or red light is transmitted. By placing the compound plate upright in a horizontal solar spectrum, beginning at the red end, the exactness of this conclusion will be demonstrated. The gradual change of hue as well as of tone may also be beautifully seen in many crystals, both natural and artificial. Blue vitriol (copper sulphate) may be readily obtained in large smooth crystals, and affords a good example of the peculiar absorption now under discussion. A crystal of this salt transmits in its thinnest parts a bluish-green hue, but gradually, as we look through an increasing thickness of blue vitriol, the blue deepens, and we are no longer able to recognise the slightest greenish cast in the colour. This change is due to the fact that a thin layer of blue vitriol transmits green rays as well as blue, while a thick layer absorbs the former, and still continues to transmit the latter. The majority of coloured solutions exhibit corresponding appearances. Good examples are furnished by solutions of potassium permanganate (Condy's Purple Fluid), potassium bichromate, chromium sesquichloride, chlorophyll, turacin, colein, and the majority of the so-called "coal-tar colours." The three first-named substances are employed in the form of a watery solution; the chlorophyll may be examined dissolved in alcohol, and may be prepared by drying nettle or beet-root leaves quickly in warm dry air, crushing them, and then macerating them in strong alcohol. Turacin, the red cupreous pigment from the wings of many species of the

African plantain-eaters, or Touracos, is best obtained in an available state by soaking a feather in weak ammonia-water. Colein may be extracted with acidulated alcohol from the stems of that well-known ornamental-foliaged plant, *Coleus Verschaffeltii;* and the coal-tar dyes may generally be dissolved in alcohol or water. A very good plan for observing the striking differences in hue between thin and thick layers of such solutions as those just mentioned was devised by Professor Stokes. A fine slit, about one-fiftieth of an inch across, between two blackened metallic edges, is adjusted vertically in a blackened piece of board; behind the slit is a source of light, such as a bright flame or a white cloud. Hold a prism, having a refracting angle of 60°, against the eye. By adjusting the position of the prism suitably a pure spectrum will be obtained, showing, if solar light be employed, the principal fixed absorption lines. Now, to observe the characteristic absorption exerted upon different rays of the visible spectrum by any liquid, adjust by a clip or elastic band, a test-tube, or flat glass cell, containing the liquid to be examined, behind the slit. Begin the observation by using a pale and weak solution, and then gradually increase the strength, noting the formation and development of dark bands or spaces in different parts of the spectrum, and the blotting out of colour after colour. If, as first suggested by Dr. Gladstone, a wedge-shaped trough be used to hold the coloured liquid behind the slit, it may be gradually moved downwards, so as to interpose thicker and thicker layers of the coloured liquid, and thus to produce the same effects as those obtained by gradually increasing the strength of the solution. Examined in a wedge-cell, chlorophyll solution is seen to begin by cutting off or absorbing, when in a thin layer, the violet, much of the blue, and some bands in the red; a thicker layer cuts off the blue, the yellow, the orange, and part of the green; and finally, in a still thicker layer, everything is extinguished save a part of the extreme end. Another liquid,

chromium sesquichloride solution, which is green in thin layers, and reddish in thick, like chlorophyll solution, owes this peculiarity to its transmission, when in thin layers, of very much of the green, a little yellow, blue, and violet, and very much of the red: increasing the thickness of the layer considerably, nothing is transmitted save a small part of the green, and a good deal of the red; everything is absorbed by a very thick layer, except the extreme red. We must not dwell longer on this very attractive topic, but the experimental methods we have described are of importance when we want to learn accurately the effect of diluting any transparent colour which is to be employed for artistic purposes. Thus it will be found that some reds when diluted, instead of becoming pink, pass through orange to orange-yellow; while some blues, instead of becoming merely paler blues when weakened, become either greenish-blue on the one hand, or violet-blue on the other. It is evident, therefore, that if a deep tint of a transparent red pigment is found to match the same colour in a natural or artificial object before the painter, it does not at all follow that the paler tones of that pigment will equally well represent the paler tones of the object to be painted.

§ 29. Thus far we have been studying white light and its resolution into colour by means of the prism and of selective absorption: we will now see how the rays of different refrangibility may be separated in another way. Some of the most beautiful phenomena of colour are produced by a modification which light undergoes when it passes the edge of an opaque body, or when it traverses a small opening. Light then turns a corner, just as a water-wave will turn the angle of a wall, or spread itself on the further side of a hole in a plate through which it has passed. This bending of the waves of light has been called *diffraction*. The source of light, in studying the phenomena of diffraction, should be a luminous or highly-illuminated spot. A silvered bead, or a steel globule, or the focus of rays obtained by the

action of a lens on a beam entering a dark chamber through a small hole: all these contrivances furnish a suitable illumination. A simple way of producing colours by diffraction is to view a bright light through a perpendicular slit one-eighth of an inch wide in a black card, holding, at the same time, close to the eye, a strip of blackened glass, on which we have previously made a fine perpendicular scratch with a needle. The scratch must correspond with the central part of the slit, which is to be kept at a distance of about three feet from the scratch. We shall see the slit in the centre, but on either side of it will appear a series of spectra, proving that the light-waves which have passed the nearer and finer slit, or scratch, do spread laterally, or are diffracted from its edges. Imagine a perfectly regular series of fine scratches on a piece of glass, and we get a diffraction grating. By it we enforce enormously the luminosity of the spectra, the various interferences and correspondences of the several waves falling at regular intervals. If fine enough, such an assemblage of slits practically cuts out at each point all but one single wave-length, and we get pure spectral colours only. If the source of light be monochromatic, or if a plate, say, of coloured glass be interposed between the light and the grating, we shall see bands of one colour only alternating with bands of black. By using, instead of a scratch, or slit, or regular grating, apertures differing in size, number, and shape, very beautiful chromatic appearances may be developed. These may be obtained by looking at a bright point or narrow line of light through a bird's feather mounted in a card frame, through a glass dusted with lycopodium spores, through a fine wire gauze, very fine cambric, or fine perforated cardboard or zinc.

§ 30. The full explanation of the production of colour by diffraction involves the study of a very complex problem, namely, the *interference* of light-waves. Though this subject cannot be adequately discussed here, the general principle which underlies all interference actions

may be easily grasped. An example drawn from liquid waves will make the cause of the phenomena clear. Two stones dropped at some distance apart into the water of a still pond will generate two sets of circular waves. At many points the waves of one set must cross the waves of the other. At some of these points the crests of the two crossing waves will coincide, and the waves will be reinforced; at other points, the same particle of water is elevated by one wave and depressed by the other—there it is at rest. A similar but not precisely identical series of inter-actions occurs, under certain circumstances, with light-waves. Take the case of a film, such as an iridescent glass film, or a soap film so thin as to show colour. Assume that a pencil of white light, S (Fig. 10), is incident at an angle on a thin plate, P, at the point I; we know that a large part will be reflected at the same angle towards R. But the rest of the beam enters the film and is refracted towards the normal to F, whence at all angles, save that of total internal reflection, a portion leaves the film finally. But the remainder of the refracted pencil is reflected to E, and thence on leaving the film is refracted to R′. But the pencil E R′ has had to traverse the film twice (from I to F, and again from F to E) before it emerges parallel with I R, and so has been retarded, or got behind I R. This retardation affects the different-coloured constituents of white light differently according to their wave-lengths, and more or less suppresses some colours, while it strengthens others. So if the film be thin enough to allow the two parallel emergent rays to be so near together that they can interfere, then colour must be produced. The particular colour at any one point will depend upon the

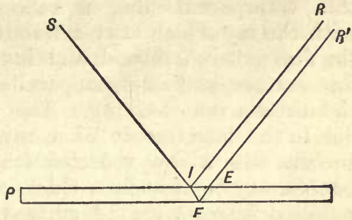

Fig. 10.

thickness of the film, and the fraction or number of fractions of a wave-length to which it corresponds. Newton's rings, seen between a slightly curved lens and a plate of glass, are produced similarly by interference, and so are the diffraction colours described in the preceding paragraph.

§ 31. We have remarked that the colours of thin plates correspond in sequence, as do those of refraction, to the colours of the prismatic spectrum. We have seen that they are produced by the interference of the ray which, having impinged upon the first surface of the thin transparent film, is reflected directly therefrom, with the ray which after refraction and reflection within the film suffers a second and inverse refraction from the first surface, and emerges parallel with and very close to the directly reflected ray. The final result is therefore due to the interference of a ray reflected from the first surface with a ray reflected from the second. A soap bubble may be of such a thickness as to retard the ray reflected from its second surface by half a wave-length, or by an uneven number of half wave-lengths. In such a case it will be found that the bubble is black, or rather dark grey, because the two reflected rays are in complete discordance, and a destruction of light ensues. Then, again, soap bubbles may, and generally do, vary much in the thickness of different parts. As the waves of light differ in length according to their hue, so they will require different thicknesses to produce accordance and discordance. The result of this is that a thickness of film which is competent to extinguish one colour will not extinguish other colours. Thin films of variable and differing thicknesses, illuminated by white light, will therefore display in their different parts variable and different colours.

§ 32. As the colour phenomena observed in soap bubbles are extremely instructive, as well as beautiful, a recipe for making a good soap solution capable of yielding long-lived bubbles may prove useful. One hundred

grains of pure potassium oleate are to be dissolved in eight ounces of recently boiled and still warm water: to the solution, when complete, six and a half ounces of glycerine are added. The mixture is left to repose, and finally filtered. In warm weather this solution may need strengthening with a few grains of Castile soap. When solution has been effected, the liquid is allowed to cool and then again filtered. Light wire rings, coated with paraffin, or glass cylinders, or paper discs, all well soaped, may be used to carry the bubbles. The solution and all the apparatus should be clean and kept warm, say at a temperature of about 65°—70° Fahrenheit.

The splendid metallic hues of the feathers of the humming-bird and the peacock and of the wing-cases of certain beetles; the rainbow hues of mother-of-pearl and many shells, of antique glass, of the precious opal, and of imperfectly polished metals—all these beautiful phenomena are due to interference, and not—at least in the majority of instances—to any actual colouring matters. We have in these objects minute surface sculpturings, or striæ, or veins, or foldings, and it is by reflections and refractions among these microscopic mechanical textures that rays capable of interfering with each other are generated. The "Iris Ornaments," or "Barton's Buttons," made by Sir John Barton, a former Master of the Mint, exhibit in marvellous perfection the splendid iridescent colours due to diffraction, and consequent interference of light. These buttons of steel are covered with minutely-engraved lines, arranged in stellar and other devices. The colours of tar or oil films upon water, and of lead skimmings, and the magnificent chromatic phenomena presented by many crystals, natural and artificial, in polarised light, are likewise due to interference.

§ 33. The polarisation of light just mentioned demands a word or two of explanation. A pencil of ordinary light consists of waves vibrating in all azimuths. By several methods it may be resolved (as in the resolution of forces) into two pencils vibrating in two azimuths

only, at right angles to each other. Such resolution is effected by (1) a doubly-refracting medium, such as Iceland spar; (2) reflection at a definite angle from a polished surface; (3) passage through certain crystals, such as tourmalines. In the case of Iceland spar, a pencil of light is split into two rays, one more refracted than the other, and having, therefore, a path of different length to travel, less or more retarded than the other. Here, then, we have two rays (vibrating in planes at right angles to one another) of identical origin, and of nearly identical path, which could interfere, and therefore produce colour, if only they could again be brought to vibrate in the same plane. This may be accomplished in several ways, notably by the introduction of a thin plate of mica between the "polariser" and "analyser." For a full description and explanation of the apparatus and its action, reference must be made to the treatises named in our Bibliographical Notes, p. ix.

CHAPTER IV.

OPALESCENCE AND TURBID MEDIA—CLOUD, FOG, AND MIST—FLUORESCENCE — PHOSPHORESCENCE — CALORESCENCE —INCANDESCENCE—COLOURED FLAMES—THE UNITY OF THE SOLAR SPECTRUM.

§ 34. When solid particles or liquid globules, which do not dissolve, are suspended in a liquid, provided the particles or globules be sufficiently fine, we observe the phenomena of opalescence. Air or any gas may similarly be rendered opalescent or turbid by the suspension therein of minutely-divided solid or liquid substances. And in the same way minute bubbles of air or gas suspended in a liquid medium may render it opalescent.

Moreover, a fourth class of examples of the same phenomenon is furnished by solid transparent bodies, in which very small particles of gas, of solid matter, or of liquid are uniformly intermixed. Provided that the medium itself be colourless, the colour and degree of transparency of the suspended particles are often of little or no account in modifying the appearances presented. Finely-divided yellow sulphur in water, black carbon particles or colourless water-spheres in air, and opaque white tin binoxide particles in glass, all produce the same result. Excellent illustrations of opalescent materials are furnished by adding a few drops of milk, or a little sodium thiosulphate followed by some hydrochloric acid, to pure water; by burning a little brown paper in air; by mingling a little bone-earth or some tin binoxide with molten glass. Fog and mist, the translucent common opal, and the so-called opal glass, are familiar examples of opalescence. Putting aside the cases in which colour is produced by the diffraction of light caused by the suspended particles, and the consequent interference of the diffracted rays, we may affirm that opalescence is caused by the scattering of light by small particles, such particles being small in size when compared with a light-wave. The general action of such excessively small particles is this, that they decompose white light, being incompetent to reflect it in its entirety, and that they scatter more of the blue and violet light which have short wave-lengths than of the orange and red light which have longer wave-lengths. The correlative effect of this *reflection* of blue and violet light is the *transmission* of orange and red light—that is, of the residual rays which have escaped reflection. So it happens that if we look *at* a turbid medium, such as milk and water, it appears blue; if we look *through* it, it appears orange or red. As the turbidity of a medium increases we have, naturally enough, a diminution of the transmitted light; but it alters in hue also, any violet and blue which may at first have escaped reflection being first cut off, and then, in succession, the green, the

greenish-yellow, the yellow, the orange. The red alone remains, and even this becomes weaker, and is finally stopped by largely augmenting the number of the minute particles present. No more telling example of this reduction of light and progressive reddening of hue can be cited than that furnished by the setting sun as it approaches the horizon, and sends to our eye beams which continually traverse layers of air in which the fine water-particles are present in ever-increasing number. The colour of its light therefore passes gradually from yellow to orange, from orange to scarlet, and from scarlet to crimson. The long receding lines of lamps in a London street exhibit the same progressive change of hue from the nearest to the farthest visible, owing to this cause. On the other hand, the blueness of the sky and of distant mountains may be traced to the larger quantity of blue rays reflected from deeper layers of a turbid atmosphere, and is the necessary complement of the above-described increasing redness. In the higher regions of the atmosphere, as among lofty mountains, and also in countries where the air is exceptionally dry, we lose these picturesque effects, which soften outlines and enhance the forms of nature with the charms of atmospheric colour. Sometimes the blueness of the light scattered by fine particles is artistically disadvantageous, as in thin washes and touches of Chinese white in water-colours. The cold bluish cast of the greys produced by adding a white to a black pigment is traceable, at least in part, to the same cause.

§ 35. The law which is followed by the chromatic absorption of turbid media was enunciated by Lord Rayleigh, and confirmed experimentally by General Festing and Captain Abney. For any ray and through any thickness the light transmitted varies inversely as the fourth power of the wave-length. So, if we have a wave-length of 6,000 in the red and a wave-length of 4,000 in the violet, then the fourth powers of these wave-lengths will be as 81 : 16, or about 5 : 1. Consequently,

if 4 inches of a turbid medium allowed $\frac{3}{4}$ of this particular red ray to be transmitted, they would allow only $(\frac{3}{4})^5$, or rather less than one-fourth, of the blue ray to pass.

§ 36. There are certain apparently transparent substances, both coloured and colourless, which exert upon the light falling upon them, or which we attempt to pass through them, a most extraordinary and unexpected effect. We refer to the phenomenon called fluorescence, the true explanation of which was discovered by Professor G. G. Stokes. A solution in weak sulphuric acid of quinine sulphate, a piece of canary-yellow uranium glass, a crystal of fluor spar, an alcoholic extract of green leaves, and a solution of the coal-tar dye called eosin, afford instances of fluorescence. The action exerted in fluorescence upon certain of the solar rays and of the rays emitted by burning sulphur or magnesium, and indeed upon certain rays emitted by a large number of luminous sources, is a change of *refrangibility*. Amongst the rays so affected by some of the above-named substances are those which lie beyond the extreme violet, and which are quite incapable of exciting the sense of vision. These ultra-violet rays of very small wave-lengths have their periods of vibration increased by the quinine solution, and becoming visible, "fluoresce" blue. But this action is not confined to the ultra-violet rays, for there are fluorescent substances which change the refrangibility, and therefore the colour, of rays already visible. And there are instances in which an already visible ray has its colour altered by a change of refrangibility in the opposite direction: namely, by long waves becoming shortened; naphthalin red and eosin are examples. It is found that the coloured light displayed by fluorescent bodies, and reflected from their particles, when it arises from the altered refrangibility of visible rays, is always betrayed by the absence of such rays from the light which they transmit. It must not be supposed that in fluorescence the incident light is *directly* changed in refrangibility. But it first causes a molecular disturbance

in the *fluorescent* body, and then this disturbance affects the waves of the ether.

§ 37. The observation of fluorescence may be simply made as follows :—Lay a piece of canary-yellow glass or a crystal of fluor spar on a piece of black velvet, and allow a sunbeam, or the beam from an electric arc lamp, to fall upon it. The transparent solid becomes filled with a splendid coloured light, quite different from that of the medium as viewed by transmitted light. As visible rays are not necessary to, and are often not concerned in, the production of fluorescence, it will be found a good plan in many cases to interpose a piece of deep blue glass in the path of the original beam, or to view the specimens in a room from which the majority of the visible rays have been cut off by means of such blue glass; the phenomenon is still clearly produced. But if we interpose a screen of canary-yellow glass, or a cell containing the quinine solution, between the light and the substances examined, no fluorescence occurs, the rays producing it having been stopped by the screen. The flame of a spirit-lamp burning a mixture of alcohol and carbon bisulphide gives but a pale blue light; but this, notwithstanding its feeble luminosity, excites fluorescence in a high degree.

§ 38. The following list includes a number of highly fluorescent bodies; most of those which occur in the liquid form may be best examined by allowing a slender stream of their solutions to fall into a jar filled with pure water on to which a beam of convergent light (using that term in its widest sense) is directed by means of a lens

Substance.	*Fluoresces.*
Fluor Spar	Green, blue, or violet in different specimens.
Uranium Glass	Yellowish-green.
Anthracen	Sky-blue.
Quinine sulphate in weak sulphuric acid	Blue.
Fraxin from horse-chestnut bark, dissolved in weak alkali . . .	Blue-green.

Substance.	*Fluoresces.*
Æsculin from horse-chestnut bark, dissolved in weak alkali . . .	Blue.
Chlorophyll in alcohol	Red.
Eosin in alcohol	Green.
Naphthalin-red, in alcohol . . .	Orange-yellow.
Fluorescein dissolved in dilute ammonia	Green.
Cyclopin in dilute ammonia . . .	Greenish-blue.

Paraffin oil, both the kind used in lamps and that employed for lubricating machinery, is very frequently fluorescent, the lamp-oil showing a blue light, and the machinery oil a green.

§ 39. Canton's phosphorus and Balmain's luminous paint afford instances of the phenomenon known as phosphorescence. Many substances after exposure to the solar rays continue to shine after removal to a dark room. Rubies, some diamonds, spodumene, the sulphides of calcium, strontium, and barium, and a large number of other inorganic substances, natural and artificial, absorb, during exposure to the radiant energy of the sun, or of an electric discharge, some of the rays, and subsequently emit light-rays of altered refrangibility. Exposure to rays of short wave-length has been found to destroy the phosphorescence of an excited surface of Balmain's paint. The nature of the light emitted by a number of phosphorescent sulphides has been examined by Lommel. He found that these bodies exhibit one or more of three maxima of luminosity—one of these being situated in the yellow, one in the green, and the third in the blue region of the spectrum. The variety of colours emitted by this class of phosphorescent bodies is traceable to the presence or relative strength of one or more of these maxima. Substances exhibiting a violet-blue colour show all three maxima; in the blue kinds the second and third are present; in the bluish-green the second maximum is conspicuous; in the orange the first maximum only. As the phosphorescence diminishes, the maxima do not always fade simultaneously, and,

in consequence of this, the hue of the emitted light is modified.

Phosphorescence is linked to fluorescence and the phenomena frequently overlap, for it is found that the duration of fluorescence is often sensibly prolonged after the source of the rays which have excited it has been withdrawn. The luminous phenomena produced by electric discharges in the highly-attenuated atmospheres of the so-called vacuum tubes, are generally described as cases of phosphorescence. Here the indirect cause of the phenomena is a transformation of electric energy, while the immediate is probably, in some measure, the change of heat into light—a change which is known as calorescence, and is described in § 40. However, some of the most beautiful phenomena of phosphorescence are undoubtedly observed when such phosphorescent bodies as those above named are exposed to an electric discharge in high vacua. Mr. W. Crookes, who has made an immense number of experiments in this way, has noted, amongst many other instances, the following cases of phosphorescence :—

Diamonds: phosphoresce red, orange, yellow, green, and blue.
Rubies: phosphoresce a brilliant crimson.
Sapphires: phosphoresce green.
Zirconium oxide: phosphoresces bluish-white.
Yttrium sulphate: phosphoresces golden-yellow.
Samarium and Calcium sulphate: phosphoresces red.

§ 40. Calorescence may be regarded as a variety of fluorescence. When all the rays of a continuous spectrum are stopped out, save the slowest waves or those of invisible heat, the "dark heat" rays that remain, after having been gathered into a focus, are competent to raise platinum foil to a visible red heat, or even to a yellow or white heat. Thus heat becomes visible as coloured light, which itself, when analysed by the prism, shows all the colours of the rainbow. There is here an increase of refrangibility, while in the normal cases of fluorescence

first investigated the actinic waves converted into light suffered a reduction of refrangibility. The mode of stopping out the visible rays in calorescence experiments consists in the employment of a cell containing iodine dissolved in carbon disulphide. Through this solution, which is practically opaque to visible light, a beam of invisible heat radiations is transmitted.

§ 41. Incandescence, the glow of a carbon filament, or of a platinum wire through which an electric current is passing, and of vapours and gases when strongly heated, is a term employed to designate phenomena of somewhat variable and complex kinds. Generally, incandescence is produced by the conversion of heat-rays, visible and invisible, into light-rays. When a ball of red-hot copper is allowed to cool slowly in the air in a dark room, it remains visible to some sensitive eyes after it has become generally invisible. Similarly, as we raise the temperature of a piece of platinum foil by means of dark heat, it will "appear" to some eyes earlier than to others. The first hue it assumes is a kind of dull chocolate-brown, representing the extreme red of the spectrum. This passes through many varieties of red and orange into yellow, and finally, by the addition of light-waves of greater refrangibility, becomes white. Thus heat-waves become light-waves, though it is not necessary that the heat-rays employed be, as in this example, originally dark or non-luminous themselves; they may be of one wave-length or of many wave-lengths, but their vibrations being accelerated and shortened, they are transformed into visible rays of all periods in the substance of the material body, which thus becomes incandescent even to whiteness, the incandescent body (such as the lime in the oxy-hydrogen blow-pipe) remaining itself unaltered chemically. The successive development of visible rays of different refrangibilities in a heated platinum wire may be beautifully seen by observing the wire through red, yellow, green, blue, and violet glasses, as it approaches full incandescence.

§ 42. The light emitted by flames is often a mixture of that derived from incandescent solids, vapours, and gases, with that sent out by substances actually undergoing chemical changes, such as oxidation. Frequently it is of very complex constitution, including rays of all refrangibilities between the infra-red and the ultra-violet—heat-rays, light-rays, and actinic rays. Frequently it presents a moderately brilliant continuous spectrum, accompanied or overlaid, as it were, by a comparatively brilliant discontinuous spectrum. Sometimes the latter spectrum is all that we can see, and it may be very simple or very complex. It is easy to illustrate this and to produce a flame which, when analysed by a prism, or better, by the spectroscope, shall show not merely an immense number of minute black spaces, like the spectrum of the sun, but broad bands of darkness divided here and there by lines of brilliant colour. The simplest spectrum which we can readily use as an illustration is that of the metal sodium. Dissolve a little common salt in some methylated spirit of wine, and introduce the solution into a spirit-lamp The flame will appear fairly luminous and of a yellow hue, slightly verging on orange. Now place, close to the flame, a narrow slit (about $\frac{1}{50}$ inch broad) in a metallic plate, and look at the slit with the prism. In order to get a pure spectrum of this, or of any other flame, a good spectroscope should be employed. This instrument—which consists essentially of a fine adjustable slit, a collimating lens to make the luminous rays parallel, a prism, or chain of prisms, made of highly refractive and dispersive glass, and a telescopic eye-piece—gives a succession of clear images of the slit, corresponding to the succession of visible rays from one end of the spectrum to the other. But with sodium the vast majority of rays are wanting, and so there is but one part of a spectrum presented to the vision. This corresponds to what is called the black line, D. Really, this line, D, consists of two firm black lines, with several faint lines between them and on either side. In the

flame of sodium, the exact spaces of these black lines of the solar spectrum are occupied by bright orange-yellow lines; these constitute the ordinary spectrum of sodium, and explain the yellow hue of its very simple light. Why these very same bright lines occur as black lines in the spectrum of the sun is owing to the fact that the light of the body of the sun loses the rays which correspond to these lines by its passage through the solar gaseous envelope, which contains sodium vapour, and is found to be opaque to the rays it emits.

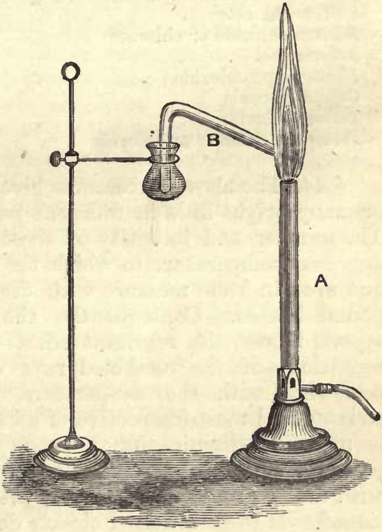

Fig. 11.

§ 43. In trying experiments with coloured flames, in order to study their effects on the appearance of differently coloured objects, or to study their spectra, the contrivance represented in Fig. 11 may be used. A is a Bunsen gas-burner (the top of which may be made of steatite); B is a bundle of fine platinum wires bound together by a spiral coil of rather coarser wire of the same metal, and dipping into a small vessel containing a mixture of a solution of the metallic salt to be experimented with and pure ammonium chloride. A ball of pumice attached to a bundle of asbestos fibres may be substituted for the arrangement of platinum wires. The following is a list of chemical compounds, chiefly metallic

salts, which impart colours of different hues to the flame of burning gas under the circumstances described.

Substance.	*Colour of Flame*
Calcium nitrate	Red.
Lithium chloride	Carmine.
Strontium chlorate or nitrate	Crimson.
Sodium chloride	Orange-yellow
Barium chloride or chlorate	Yellow-green.
Boracic acid	Green.
Thallium perchloride	Green.
Copper chloride	Blue-green.
Indium chloride	Indigo-blue.
Potassium chlorate or chloride	Lavender.

§ 44. The above substances give spectra having few or many bright lines in different parts of the spectrum. The number and intensity of these lines differ with the degree of temperature to which the materials are raised, and even in some measure with the nature of the compound heated. Consequently, the exact hue of the several flames, the resultant effect—that is, as a colour-sensation—of the combined rays of each body differs somewhat with the temperature. One of the most striking and most instructive of all experiments on colour is made by illuminating a bouquet of flowers, an oil painting, or a painted representation of the solar spectrum with the light emitted by any of the flames we have mentioned. If these coloured objects do not receive the particular coloured rays which they are competent to reflect, and to which their hue in ordinary white light is owing, they become dingy, or even black. The most brilliant blues, violets, and reds show no colour in the yellowish illumination of the sodium flame, and the human face exhibits a ghastly yellowish-grey pallor. We shall describe in a subsequent chapter (Chap. XII.) many other important modifications in the appearance of coloured objects, caused by variations in the components of the light with which they are illuminated. But this one experiment with light from a lamp burning spirit containing common salt,

or from a Bunsen gas-burner encircled at the lower part of its flame with a collar of rock-salt, is amply sufficient to demonstrate the complete dependence of the varied colours of objects upon the presence, in the light by which they are seen, of those particular coloured rays to which they are responsive, and which they have the power of irregularly reflecting.

§ 45. What has been already said in the present chapter as to the changes of refrangibility effected by certain materials in the rays of dark heat, of actual light, and of invisible actinism, will have prepared the reader to accept the true view as to the essential unity of such a spectrum as that of the sun or of incandescent lime or carbon. The notion that the spectrum of the sun is a triple one, consisting of a heat spectrum, a light spectrum, and an actinic spectrum, partly superposed or overlapping each other, cannot be maintained. True, there is a region where the thermal effect is greatest, another where the luminosity reaches its maximum, and a third where the chemical action is most pronounced. But these facts, taken in connection with the changes of refrangibility occurring in calorescence, fluorescence, &c., and with the observation that all the rays, visible and invisible, thermal, luminous, and actinic, obey the same laws of reflection, refraction, polarisation, &c., negative the idea of three distinct spectra. The rays from the infra-red to the ultra-violet differ solely in their periods of vibration —in the length of their waves. The diverse effects which they produce are due to the specific adaptation of particular rays to produce certain effects. More than this, for one single ray, of perfectly definite wave-length and position in the spectrum, may produce a rise in the thermometer, a sensation of colour, and a chemical change in a sensitive substance. And these effects may, and do, occur without any necessary change of refrangibility in the active ray. Its motion, appropriately transferred from the ether to material molecules, is heat, light, actinism. Of course, innumerable cases occur in which

the motion of a ray is stopped by a material substance, and is commonly said to be quenched or absorbed. It is not lost, however difficult it may sometimes be to trace its effects. Thus, a solution of alum in water is almost impervious to heat-rays, a clear crystal of rock-salt is almost perfectly transparent to them all. The impervious liquid is warmed by the rays it cannot transmit, while the rock-salt remains but little altered in temperature by their free passage. Invisible chemical rays are quenched very largely by glass, but pass freely through quartz: no chemical change occurs in either, but the glass rises in temperature. Again, there are other cases in which heat-rays and light-rays absorbed or quenched by certain media are transformed into actinism.

CHAPTER V.

THE CONSTANTS OF COLOUR—HUE, PURITY, AND LUMINOSITY OF COLOURS—SHADES, TINTS, AND TONES—BROKEN COLOURS—CLASSIFICATION AND NOMENCLATURE OF COLOURS.

§ 46. The one characteristic of any colour which first appeals to the eye, and first demands consideration, is its *hue*: we endeavour to *name* the colour, be it red or orange, green or blue, violet or purple. When we are dealing with the solar spectrum, or with the continuous spectrum of incandescent carbon or lime, we can identify each colour (that can be separately recognised) by means of its wave-length or refrangibility. We can isolate a small coloured strip in the solar spectrum, and fix its position by a reference to neighbouring fixed lines. We can follow the same course with the several constituents of the bright line spectra of lithium, sodium, &c.; but when a colour, as it affects the eye, is made up of several

rays, or groups of rays—when its constitution is complex—this method fails. For instance, there is not in any spectrum a hue which can be called purple—there is no wave-length of any single ray which corresponds to the ocular sensation of purple. That sensation may be excited by the combined or simultaneous action on the retina of red and blue waves, or of red and violet waves; we have only to mix lights of these colours in proper proportions, and we get purple; but it is clear that we are unable to fix its spectral position. And this statement leads to another point of importance. Many of the colours which we perceive both in luminous and illuminated bodies, although they may appear identical in hue with particular portions of the spectrum, yet are found, on examination, to be not simple, but compound: not to consist of rays of one refrangibility only, but of a number of rays having different wave-lengths, but producing on the eye a resultant effect, exactly the same as the corresponding simple ray of the spectrum. Thus, there is a compound yellow, containing red and green waves; a compound blue, containing green and violet waves; a compound orange, containing red and yellow waves, but each of these three compound hues may be exactly matched by a simple hue in the spectrum.

§ 47. The second constant of colour is *purity*. A colour is said to be pure when it is unmixed with white. A pure colour is not necessarily a bright colour, for many bright colours contain a large admixture of white. Nor are pure colours always strong, rich, and deep, for there are parts of a pure spectrum where colours may be observed (wholly unmixed with white light, and having, of course, perfectly definite wave-lengths) of so weak a tone as to be recognised with difficulty. In a spectrum of the sun, or of any ordinary white light, as usually obtained by using a single prism, unless special precautions be taken, there will always be some white light. And in pigments and coloured objects the proportion that the white light bears to the coloured will often be much

larger than we expect. The colours of vermilion, emerald-green, and ultramarine are not pure in the sense in which this term is employed to designate one of the three constants of colour; for if we compare a strip of paper, painted thickly with vermilion, with the nearest corresponding colour of a pure and complete spectrum, we shall find that we can match its *hue*, but that it looks paler. To make the two colours correspond, we must add white light to the spectral red, to the extent of about one-fifth of the amount of the latter. In other words, we ascertain by this means that the red light reflected from vermilion is not "pure" red, but contains in one hundred parts about eighty parts of red and twenty parts of white light. Of course, much depends upon the way in which the surface of the pigment is prepared, and the medium in which it is mixed. A nearly matt surface of vermilion ground in copal varnish, oil, and turpentine reflected seventeen parts of white light to eighty-three of red.

§ 48. It is of importance to remember that the addition of white to colour alters its hue, and does not make it merely paler. The addition of a very small quantity of white light to coloured light (1 part to 360) can be recognised by the eye in the paler tint produced, but it requires a much larger addition to bring about a perceptible change of hue. Increase of brightness also alters the hue, as fully described in §§ 119 and 120.

§ 49. *Brightness*, or *luminosity*, is the third colour-constant. It is measured by the total amount of light reflected to the eye, and is therefore independent of purity and of hue. It is sometimes spoken of as "clearness." If a given colour be at once perfectly pure and perfectly bright, it is saturated. The comparative brightness of the different hues in the solar spectrum depends in a measure upon the thickness of the atmospheric layer through which the sun's light has penetrated previous to its prismatic analysis; the state of the atmosphere, in respect of dissolved water-vapour, and suspended water and solid particles, also greatly affects this relative brightness.

Thus, while the total brightness of sunlight is reduced by the depth of the atmosphere, the brightness of its several constituents is unequally affected, the red rays suffering the least diminution. Vierordt made a series of observations on the relative brightness of the several main colours of the solar spectrum; the results he obtained have been re-calculated by Rood, for a prismatic spectrum divided into 1,000 parts between the fixed lines A and H. Rood, moreover, has named the several coloured regions, so that with these two data (of spaces and luminosities) he has been able to construct the following

Table showing the Amounts of Coloured Light in 1,000 *Parts of White Sunlight.*

Red	54	Green and Blue-green	134
Orange-red	140	Cyan-blue	32
Orange	80	Blue	40
Orange-yellow	114	Ultramarine and Blue-violet	20
Yellow	54	Violet	5
Greenish-yellow	206		
Yellowish-green	121		

These numbers are, then, the product of the respective areas into their corresponding luminosities. And we find, on examining the spaces of the spectrum occupied by individual colours, that some of the narrowest give very high figures, owing to their great brightness. Thus the pure orange-yellow, about the line D, corresponding in area to no more than 1·12 per cent. of the whole spectrum, exceeds in luminosity all other regions. Captain Abney has more recently arrived at a similar result by an original and ingenious photometric method. He found, at an elevation of 8,000 feet, on the Riffel Alp, that the region of intensest luminosity in the spectrum was shifted somewhat farther still beyond the line D on the more refrangible side, when compared with its position as observable at low levels; the degree of luminosity was also greater in every part of the spectrum save the red.

§ 50. By means of Maxwell's rotating sectors, Rood has determined the luminosity of several pigments in common use. He mounted, upon a disc painted with the pigment to be tested, a smaller compound disc of black paper, with a white sector, the area of the white sector being adjusted till the grey, produced on rotation by its ocular combination with the black, exactly matched in luminosity the coloured disc which formed the background. A correction having been made for the small quantity of white light reflected by the black paper itself, the following degrees of luminosity were obtained (the author adds four observations of his own, which are distinguished by an asterisk)—

Substance.	*Luminosity.*
* Zinc-white	110
White Paper	100
* Whatman's Paper (not hot-pressed)	97
Pale Chrome-yellow (water-colour wash)	80·3
Pale Emerald-green (in thick paste)	48·6
Cobalt-blue (water-colour wash)	35·4
Vermilion (in thick paste)	25·7
* Natural Ultramarine	9·1
Artificial Ultramarine	7·6
Black Paper	5·2
* Lampblack	·8

These numbers represent, of course, the comparative luminosities merely of the particular specimens examined, the results varying considerably with different preparations, with the mode of applying, and the thickness of the layers of pigment. Nor must it be supposed that in the case of any coloured pigment the reflected light is "pure." With chrome-yellow, for instance, the light measured is not yellow only, but contains much orange-yellow and greenish-yellow, as well as orange, red, and even green light. But the total ocular effect of all this mixed light is yellow. With black paper, however, and with lampblack, the small quantity of scattered light they send out is nearly, if not quite, white.

§ 51. Having acquired a clear conception of the three constants of colour—namely, hue, or colour *par excellence*; purity, or freedom from white; and brightness, often called luminosity, or the quantity of optical sensation caused by a given area—we are now in a position to define the meaning to be attached to such expressions as tones, tints, and shades, as applied to coloured substances. Tones are estimated by the absolute amount of colour-sensation they excite: they may be grouped into three series for every possible hue or kind of colour, according as these hues are admixed with white, with black, or with both black and white, or grey. Apart from any alteration of hue which may occur by such admixtures, we may affirm that we weaken or reduce a normal colour by the addition of white, producing a scale or series of tones from deep to pale; that we darken, but do not deepen, a normal colour by the addition of black. Tones belonging to any of the above series are commonly spoken of as shades, but it is better to limit the use of this term to admixtures with black. A scale is a regular series of such tones as those which have been defined above. So each hue admits of three scales.

1. The *reduced* scale—that is, the normal hue mixed with progressive increments of white, thus forming *tints.*

2. The *darkened* scale—that is, the normal hue mixed with progressive increments of black, thus forming *shades.*

3. The *dulled* scale—that is, the normal hue mixed with progressive increments of grey, thus forming *broken tints* (commonly called "greys").

§ 52. There are two ways of preparing a series of tones belonging to each of the scales, assuming that we are dealing with pure pigments, and not with coloured lights. If we wish to obtain a scale of ten tints of vermilion, we may mix a given weight, say ninety-five parts of that substance, with five parts of zinc-white for the first tint, ninety parts with ten for the second, eighty-five with fifteen for the third, and so on, up to fifty parts with fifty for the tenth tint. Or we may

take a paper disc, painted with vermilion, and add to it, by means of one of Maxwell's graduated white sectors, the above areas, or amounts of white (assuming the circle to be divided into one hundred degrees), each five parts of white added covering up five parts of vermilion. On rotating the compound disc, we shall obtain ten concentric rings, the outermost being like that of vermilion when mixed with white to the extent of five per cent., and the innermost being the palest tint of the scale, and

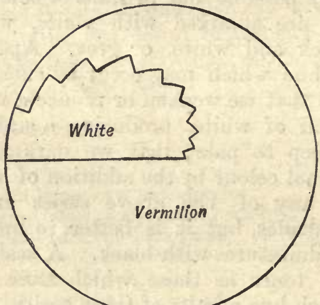

Fig. 12.

containing fifty parts of white in the hundred : the compound disc, when at rest, is shown in Fig. 12. A similar sector of black will yield ten corresponding *shades* of vermilion : a grey sector will yield a "broken" scale of ten tones. But by neither of the processes do we obtain scales of the exact normal hue from which we start, for this hue alters with each increase of luminosity (as in adding white), or by each diminution of luminosity (as in adding black). But we do not now dwell on this matter further, as it will be fully studied in Chapter XII., and has been already touched upon in § 48.

§ 53. Many attempts have been made to classify colours, including under that designation not only all hues, with their shades, tints, and broken tints, but also

white—a balanced or neutralised compound of two or more hues—and black—the negative correlative of light and colour. In its simplest form the scheme of classification may be tabulated thus :—

DARKNESS	. . .	Black.
LIGHT	*Colourless* . .	White ; Greys, or Shades of White.
	Coloured . .	Hues ; Tints and Shades of Hues.

The real difficulty begins when we attempt the classification of hues : that is, of colours proper. Where can we find standards of comparison for all colours in respect of the three constants of colour—hue, purity, luminosity? If we start from the solar spectrum, disregarding the absence from it of all the purples, shall we employ the prismatic spectrum, or that obtained by diffraction? In either case we shall not thus obtain a constant standard of luminosity, since the brightness of the various spectral hues differs enormously. What the spectrum does furnish us with is a series of well-defined hues, of which the exact positions and wave-lengths are ascertainable, and to which reference can at any time be made. It is even possible to compare the hues of a very large number of pigments with these fixed spectral hues, and to determine thereby their position in the normal spectrum. Thus, Professor Rood has ascertained the position (and consequently the wave-lengths) of the hues of several important pigments. Adopting the normal spectrum and dividing that part of which which lies between the lines A and H into 1,000 parts, he finds the position of vermilion to be at 387, that of emerald-green at 648, of cobalt-blue at 770, of lapis-lazuli at 785, and of artificial ultramarine at 857.

§ 54. The difficulties in the way of classifying colours are augmented by the very great number of hues, with their shades and tints, possessed of varying degrees of

luminosity, which the human eye is competent to distinguish. From experiments, in which small quantities of one coloured light were added to another or to white, Aubert calculated that fractional quantities of light, varying from $\frac{1}{100}$ to $\frac{1}{300}$, produced recognisable differences, and that a thousand hues could be distinguished in the solar spectrum. Add to these the hues produced by gradual increments or decrements in luminosity and the whole series of purples, and we reach a grand total of colours which must be measured by hundreds of thousands.

§ 55. These high figures alone preclude the possibility of assigning names to any hues but those which are well known, and are separated by considerable intervals of wave-length. The dearth of well-defined colour-names in English, and the want of flexibility in the language as to the coinage of new designations, makes the question of colour nomenclature a most difficult one. Moreover, there are some words expressive of colour which are so vaguely assigned, in common parlance, that when we hear, for instance, of "purple" we are not sure whether a rich blue, or a red-violet, or even a deep red is meant. Chevreul's graduated series of chromatic circles, containing a set of typical hues, with their progressive admixtures with white and with black, requires very considerable corrections as to many of its chromatic intervals, and as to its assumption with regard to the relations between yellow, green, and blue, before it can be even provisionally accepted as affording a basis for colour nomenclature. Radde's Colour Chart, with its 882 hues, though nominally based on the colours of the solar spectrum, is essentially that of Chevreul. It lacks precision as to the places in the spectrum from which the normal hues are taken, while its attempted realisation by the chromo-lithographic process is very far from being a success.

§ 56. Many attempts have been made to construct colour-charts, both for coloured lights and for coloured materials, such as pigments, by the aid of geometrical

figures. Two triangular pyramids set base to base, the sphere, the cone, the circle, the cube, and the triangle, have all been employed for this purpose. The triangle, as arranged by Maxwell, with the modifications introduced by Rood, yields results as satisfactory as any that can be obtained with a figure of one dimension. Mr. W. Benson's colour-cube presents many advantages over any plane figure; its defects and limitations will be best understood after a brief description of it has been given. At one solid angle of the cube, black, or the absence of light, is placed; at the opposite solid angle, white. At the three solid angles nearest to black the full red, green, and blue are respectively placed; in the corresponding and opposite corners nearest to white the three secondaries occur: namely, sea-green, pink, and yellow. The centre of the figure is occupied by grey: that is, by white of moderate brightness, half-way between black and white. A few examples of the position of particular hues on and within this cube will serve to show the principle underlying its arrangement. Thus, in the middle of the edge joining red to black occurs "dark red," other shades of red (red of lowered brightness) being found along the same line. Half-way between the solid angles occupied by red and yellow is the normal orange; half-way between yellow and white is pale yellow: that is, a tint of yellow, mingled with much white. Along the axis which joins the opposite corners red and sea-green, occur various tints of these two colours, in which one or other preponderates over the white which these complementaries produce by their union, except at the middle point, which is also the centre of the cube, where a neutral grey is found. And here it is that we meet with certain defects of this colour-cube. For theoretically, at some point along this axis, where equivalents of red and sea-green coincide, true white ought to be found, and if, as in Mr. Benson's primary assumption, the "intensities," that is, the brightnesses, of the three primaries be equal, then the centre of the cube must be occupied by white;

but this is not the case. In this inconsistency, and in the incorrect assumptions that the intervals between the primaries are equal, and that the brightness of the primaries is identical, we see the defects and the limitations of this and of similar arrangements. And if we replace coloured lights by pigments, we shall find that it is impossible to locate the hues, brightnesses, and purities which they represent anywhere near the points theoretically assigned to them. But after all, this colour-cube furnishes a large number of most interesting and beautiful colour arrangements when we examine the hues situated in sections of the cube taken at right angles with its principal axes, while its defects are inseparable from solid forms bounded by plane surfaces. And there can be no question that this mode of classifying colours has conspicuous merits, when regarded from what we may call a qualitative rather than quantitative point of view.

A few words concerning the colour-cone of W. von Bezold may be fitly introduced here. Its apex is black, the centre of its base white; along the axis greys of every shade will occur. Normal colours of full brightness are located at certain points on the circular boundary of the base, following the precise order of their refrangibility, and passing by insensible gradations from one hue to another, purple uniting the violet with the red end of the spectrum. The exact angular position of each of these hues can be determined (see § 78), and they can be placed in strict conformity with such determination—an arrangement obviously impossible in the case of the cube. Then the lines which pass through the centre of the base will be found to join complementary colours; in fact, this circular base constitutes a true chromatic circle. Here, however, the theoretical position of the white in the centre is not correct, for it assumes that the neutralisation of all complementaries is effected by their union in equal quantities. On the exterior of the cone, as we ascend, we find the darkened tones or shades of each hue; the basal plane exhibits, as we proceed towards its centre,

mixtures of each normal hue with increasing quantities of white. A horizontal section of the cone, taken, say, at half its height, will show each hue admixed, as we near the axis, with increasing quantities of grey. The positions of the colours on the surface of the cone are, as we have previously stated, so adjusted that a line meeting the axis at right angles, and drawn from any one point on the exterior, will meet, on the opposite surface, the position occupied by the complementary. A tetrahedron may be substituted for this cone with some sacrifice of accuracy, as the angular values of the several hues must be ignored. We assign black, red, green, and blue to the four solid angles of the figure, white to the centre of the face opposite to black, and grey to the geometrical centre of the figure. Somewhere along the edge, joining the red (R) with the green (G), we shall find bright yellow

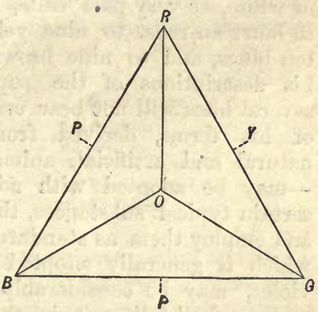

Fig. 13.

(Y); between the green and the blue (B), sea-green (S); between the blue and the red, purple or pink (P). We use the above expressions (bright yellow, sea-green, pink) because when we are dealing with colours such as those which are obtained, as we shall presently see, by the union of two lights, the resultant hue must be brighter, that is, more luminous, than either of the constituents—must have the combined brightness of both. Now, the only way readily available for expressing this added brightness lies in the use of terms which imply a lighter hue—a hue more nearly approaching the brightness of white, though not in reality mixed with white. In fact, these combined hues may be said to be much farther on the road towards the brightness of white than

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are their separate constituents. This statement, with the meanings to be attached to some of the terms just introduced in the present paragraph, such as primary, secondary, and complementary, will be fully explained in the next chapter.

§ 57. A few words may now be said concerning an old attempt at naming colours, which was first made so long ago as 1774 by the mineralogist, Werner. His system included ninety-two terms, arranged in nine groups. He gave names to ten "metallic" colours, to six varieties of white, or very pale tints, to six greys, to five blacks, to fourteen reds, to nine yellows, to thirteen greens, to ten blues, and to nine browns. His classification and his descriptions of the supposed constituents of the several hues will not bear critical examination, but some of his terms, derived from well-known materials—natural and artificial, animal, vegetable, and mineral—may be adopted with advantage. One may select certain typical substances, the hues of which vary little, and employ them as standards for reference. This plan, which is generally adopted with regard to orange and violet, may be considerably extended with advantage, and we shall follow it in the remaining chapters of the present work. To give an idea of Werner's nomenclature, we now cite the ten terms employed to designate the varieties of blue :—

1. Blackish-blue : blue mixed with black.
2. Azure-blue : a very bright, rather reddish blue.
3. Violet-blue : a pure mixture of red and blue.
4. Lavender-blue : violet-blue mixed with ash-grey.
5. Plum-blue : a reddish violet-blue, with brown.
6. Prussian blue ; the purest blue.
7. Smalt-blue : a pure but pale blue.
8. Indigo-blue : a dark blue, with black and green.
9. Duck-blue : blue, with a great deal of green and a little black.
10. Sky-blue : a bright, rather greenish blue.

Now there is scarcely a single description amongst these hues which does not challenge criticism, even apart

from the general lack of orderly sequence and of precision which they exhibit. Lavender-blue and indigo-blue may perhaps pass muster, but what are we to say to the definition of Prussian blue as the purest blue, when it clearly shows the presence of more than traces of green? Lapis-lazuli finds no place in the list, although it was, of course, well known to Werner, and furnishes an admirable standard of the normal blue.

In order to furnish an illustration of how the hues of natural substances, belonging to the three kingdoms of nature, may be utilised in naming colours, we may cite a few of the materials which represent the range between red and yellow:—

1. Chinese Vermilion.
2. English Vermilion.
3. Orange Vermilion.
4. Red Lead.
5. Saffron (dry).
6. Orange-peel.
7. Gold (pure).
8. Amber.
9. Straw.
10. Gorse-flowers.
11. Lemon-peel.
12. Sulphur.

Quite recently, another attempt at naming and classifying colours has been made by R. Ridgway. The small volume which he has prepared is intended primarily for the use of naturalists, but it possesses one feature at least which is likely to be appreciated by many persons interested in decorative and pictorial art. This is a comparative vocabulary of colour-names, giving in parallel columns, on nine double pages, the equivalent words in English, Latin, German, French, Spanish, Italian, and Norwegian. The most striking characteristic of the book is, however, a series of coloured plates. Each of these plates has been planned with skill and care, and executed in water-colour pigments of considerable or complete stability. There will certainly be diversity of opinion as to the justness of the application of many of the names to the actual colours given. But to name tints, hues, and shades, instead of merely numbering them, constitutes a step in the right direction. Till an

"International Standard-Colour Conference" of artists and scientists has finally agreed upon the names to be given to a couple of hundred different hues, reproduced in enamel, and preserved for reference, like our standards of weight and measure, we must be grateful for any attempt, even though it be but partially successful, in the way of a consistent and complete nomenclature. As an example of Mr. Ridgway's sets of colour-names, we may cite those which he assigns to twenty hues, lying between red and blue, and belonging to the group of purples :—

1. Prune.	8. Aster.	15. Wine-purple.
2. Dahlia.	9. Maroon.	16. Lavender.
3. Auricula.	10. Violet.	17. Solferino.
4. Plum.	11. Phlox.	18. Heliotrope.
5. Pansy.	12. Pomegranate.	19. Lilac.
6. Indian Purple.	13. Mauve.	20. Rose.
7. Royal Purple.	14. Magenta.	

The mere inspection of this list suffices to show that although there may be a judicious selection of colour-names here, there is nothing approaching to a scientific classification of them.

CHAPTER VI.

THE MUTUAL RELATIONS OF COLOURS—COMPLEMENTARY COLOURS—YOUNG'S THEORY OF THREE PRIMARY COLOUR-SENSATIONS—THEORIES OF HELMHOLTZ, CLERK-MAXWELL, W. VON BEZOLD, ROSENSTIEHL, ROECHLIN, AND OTHERS—ABNORMAL PERCEPTION OF COLOUR—COLOUR-BLINDNESS.

§ 58. WE have seen (§§ 19—21) that the several colours of the solar spectrum, if by any means they be re-united, reproduce white light. It is not necessary, for this

purpose, to divide the colours into seven, or any other particular number of groups, and then combine them; it will suffice to separate the spectrum into two sections, equal or unequal. And, we may go further, choosing two, three, or more of the colours of the spectrum, and leaving the whole of the remainder, and yet we shall find that, with the few chosen portions, we get white light, diminished, it is true, in brightness, but quite free from colour. The three conditions to be fulfilled in order to reach this result are these: that the brightness, the quantity and the spectral position of the several selected hues shall have certain definite relations. Let us assume that we have chosen three such spectral hues; then, if we combine two of them, we shall obtain a colour, which, united with the third hue, will form white. Such pairs of colours, one compound, the other simple, are on this account called "complementary." It is obvious that an immense number of such complementaries must exist. Their study is of great importance to artists, and especially to workers in the so-called decorative or ornamental arts, for a knowledge of the strength of contrast in colour depends upon a right appreciation of the true complementaries.

§ 59. There are many ways of producing, side by side, complementary colours. The *Schistoscope* of Brücke is perhaps the best instrument for this purpose. It consists essentially of an eye-piece, containing a plano-convex lens, and a rhomb of calc-spar, a diaphragm with a very small square opening, and a Nicol's prism. A large number of very thin laminæ of selenite should be provided. One of these, if laid on the diaphragm, will, when the instrument is properly adjusted, produce differently-coloured images of the square opening, lying close together. The colours of the pair of images are always complementary, and if the selenite-films are sufficiently thin, the colours will be bright and saturated. The two images are polarised in opposite planes. The following list includes a few of the more important:—

Pairs of Complementary Colours.

Red .	Blue-green.	Yellow-green .	Violet.
Orange .	Turquoise.	Green . .	Purple.
Yellow .	Lapis-lazuli.	Green-blue .	Carmine.

It is a good plan, when a pair of complementaries has been obtained, to imitate it as nearly as possible by means of water-colours on white paper.

§ 60. In order to obtain the true complementaries of the darkened and dulled hues, such as chocolate, olive, russet, lavender, &c., so commonly occurring amongst pigments, Brücke's Schistoscope is useless. We may in such cases use Dove's achromatic calc-spar prism. We place a small square piece, say of chocolate-coloured paper, on a background of black velvet: near it we place another piece of paper, painted with a broken blue-green. The prism will enable us to see whether the part of the two images which overlap yields a pure neutral grey: if it does not we must add to the second slip a little more of the pigment which is necessary to complete the trial hue, perhaps a little more green or a little more blue will be needed. A more exact and easier method consists in the employment of Maxwell's rotating sectors. A small combined black-white disc is mounted on the axis, and behind it are placed larger discs of the two pigments which are known to be necessary to make the complementary of the hue under examination. A disc painted with this hue is to be associated with the two others, and the proportions of the three are to be so adjusted, by means of the radial sectors, that on rotation the whole makes a neutral grey, the neutrality of which can be gauged by its correspondence with the central black-white disc, which should contain about 75 per cent. of black Rood, operating in this way, determined that the complementary of a dull yellow, like that of brown pasteboard, was obtainable by combining forty-five parts of artificial ultramarine with fourteen parts of emerald-green. This mixture equalled forty-one parts of the dark yellow in question, and the whole corresponded on

rotation to a mixture of twenty-four parts of white with seventy-six of black. Certain adjustments have, of course, in every case to be made, in order that the complementaries may have equal brightness. With some pigments, however, such as carmine, vermilion, and Indian yellow, it is not possible to compare complementaries of equal brightness and saturation, as the optical constituents of the pigmentary complements of these substances do not correspond to them in brightness and saturation. Thus, we must add a black sector to a vermilion disc to get its true complementary in brightness, as well as hue, by rotating together green and blue sectors. White sectors must also be introduced in certain cases of the comparison of pigments, in order to introduce white light into one or other of the pairs of complementaries, and so to equalise their tints.

§ 61. The question as to the true meaning to be attached to the term primary, as applied to colour, may now be discussed. Every ray of differing refrangibility in the visible part of the spectrum is in one sense a primary colour, for it is simple and excites a definite sensation. But there are many reasons, mainly connected with the structure and functions of the eye, which have led to the selection of certain coloured lights—generally three in number—as yielding primary colour-*sensations*. This primariness is then not objective, but subjective in respect of human vision. Wünsch, a German physicist, was the first to select, in 1792, the three so-called primaries which are now generally accepted as best fulfilling the conditions of the case. Dr. Thomas Young, in 1802, after first fixing upon other sets of three hues, independently decided upon the triad of Wünsch, and propounded a very reasonable theory of the cause of colour-vision. In recent years, Helmholtz, Maxwell, and Rood, as well as many other physicists, have developed the theory of Wünsch and Young, and have adopted the same, or very nearly the same. triad of primary colour-sensations. These three fundamental hues, or primaries, as we will for

brevity's sake call them, represent three widely separated and very bright colours of the spectrum. The earlier experimenters possessed no means, beyond mere verbal description, of exactly localising the spectral hues they had selected. Maxwell and Helmholtz, and other observers, on the contrary, have assigned particular positions, in relation to the solar fixed lines, to the several members of the triads they employ. It must not be supposed that there is not a measure of arbitrariness and some slight variety in the selection of the primaries. Young simply adopted red, green, and violet. Helmholtz first chose a red not far from the end of the spectrum, a full green near the middle, and a violet not far from the more refrangible limit of the spectrum. Maxwell adopted a scarlet-red with a tinge of orange like orange-red vermilion, lying in the spectrum one-third of the way towards D, between the line C and D. His green is to be found at one-quarter of the distance from E, between E and F, and resembles emerald-green in hue. For his third member Maxwell selected a blue-violet, midway between F and G, which is fairly imitated by the best sorts of artificial ultramarine. Other investigators have selected for their fundamental green a slightly bluer hue; others, one more nearly approaching a yellow-green. On examining a map of the spectrum, and experimenting with the spectrum itself, it will be evident that if we select an orange-red, we shall have to choose a blue-green and a full violet, in order to secure a properly adjusted triad; and that, on the other hand, if we choose a full pure red, we must accept a pure green, and a very nearly, if not quite, pure blue to complete the group, all the selected hues being shifted, so to say, towards the red end of the spectrum. For reasons which we hope to make clearer by-and-by, we will adopt the names red, green, blue, for the three primaries, which, with some slight modification, are now generally accepted.

§ 62. There are many ways of mixing together the three spectral lights which we have assumed to be the

three primaries. But if we desire to mingle two only we shall find it a good plan to place small adjustable mirrors in the selected spectral regions, and to throw the lights they reflect on to a screen. Or we may use a V-shaped right-angled slit in order to obtain two crossing spectra, and then from these, by the aid of suitable diaphragms, we may cut out all the colours not required. Assuming, then, that we have at our disposal beams of light of these three colours, perfectly free from white light, and having considerable but not excessive brightness, we may represent the results of mingling two or all three of them in the form of a diagram, with overlapping bands, triangles, or discs. The last arrangement, first devised and employed by Mr. W. Benson, in his "Principles of the Science of Colour" (Chapman & Hall, 1868), is shown in Fig. 14. In the lower part of the figure we begin by a black surface, upon which we assume that there are thrown simultaneously three discs of light—namely, one of red, one of green, and one of blue. These discs all partially overlap each other, thus exhibiting the successive additions to darkness of each one of the primary colours, of each pair of them, and, in the centre, of all three of them. Where the red and the green discs coincide the resultant hue is yellow, the green and blue united make blue-green or sea-green, while the blue and the red together form bright purple or pink. The central space where red, green and blue overlap is white. The brightness of this white area must of necessity equal the sum of the brightness of its three component lights—red, green and blue—and is roughly represented by the white paper in Fig. 14. But in the case of the three twofold, or secondary colours—yellow, green-blue or sea-green, and purple or pink—we are forced, in a painted diagram such as ours, to represent their increase of brightness by adding white to them ; that is, by reducing their purity or saturation, as we cannot raise the luminosity of pigments. So *pale* colours or tints are used to illustrate the important fact that coloured *lights*, when commingled,

increase in brightness. And it must not be forgotten that not one of the pigments we have been compelled to employ in Fig. 14 (and in our other coloured diagrams) offers more than a rough approximation to the true hue which it is assumed to represent. In the upper part of

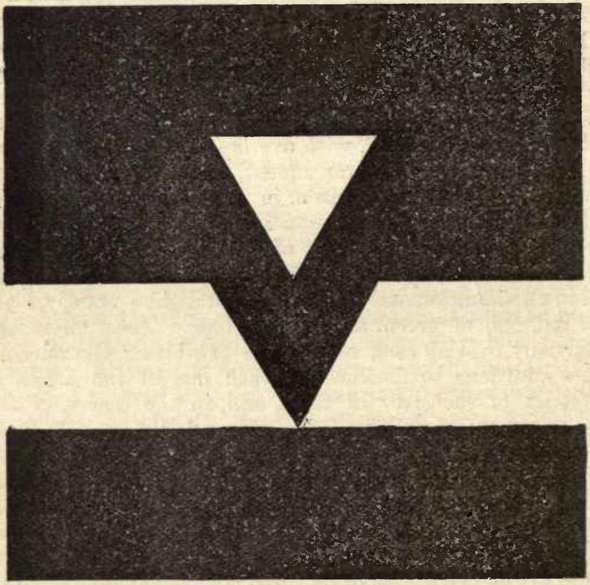

Fig. 15.

Fig. 14 we represent the changes of hue and the reductions in brightness which take place when from white successive subtractions of one, two, or all three of the primaries are made. Both parts of the diagram show also the three pairs of the chief complementary colours, red being opposed to green-blue, green to pink, and blue to yellow. All transitional hues have been purposely

excluded from this diagram, for they cannot be fairly represented by any system of colour-printing. But it is of great interest to possess a ready means of seeing them. For this purpose a white triangular space on a black ground, associated with a black triangular space on a white ground, and arranged as shown in Fig. 15, is to be viewed at a considerable distance through a prism with its refracting angle turned away from the eye. That edge must be so placed as to bisect both triangles; the figure should be at least a foot across, and is best made by placing three accurately-cut pieces of white cardboard, or white paper painted with permanent white, upon a surface of black velvet. The oblique sides of the white and black triangles will be covered with a regular succession of colours belonging to one or other end of the spectrum. In various parts of the central region these two half spectra will overlap, producing every possible intermediate hue. The arrangement shown in Fig. 15 is due to Mr. W. Benson. By means of various similarly constructed figures of black and white, with triangles, bands, and crosses of white upon black, an immense number of most beautiful dispositions and combinations of spectral colours and their complementaries may be obtained: a white V-shaped figure on a black ground is one of the simplest and best arrangements of this class.

§ 63. We return once more to the consideration of the coloured diagram (Fig. 14), in order to point out certain additional facts which it may serve to elucidate. If, for argument sake, we assume that the brightness of each primary hue is the same (and this is, of course, true neither of the spectral colours, nor of their representatives amongst pigments), or, if we assume that it is unequal, in either case we shall observe that the brightness of the three compound or secondary colours, *taken together*, is equal to twice the brightness of the white made up by the union of the three primaries. In point of fact the brightness of each of the three secondary colours, as represented by our ordinary pigments, differs

greatly. Thus the emerald green which we may use in copying Fig. 14 is much brighter than any vermilion, and the vermilion again is still brighter than the ultramarine. Consequently, the yellow, which we here assume to be formed by the union of the green light from the emerald green with the red light from the vermilion, must be brighter than the pink similarly produced from vermilion and ultramarine, while the green-blue or sea-green takes an intermediate position. Adopting Rood's brightness-co-efficients for the several pigments (see § 50), we arrive at the following approximate values for the three secondary colours, white being taken as 100 :—

Yellow = 74·3. Sea-green = 56·2. Pink = 33·3.

On adding the brightness of their several complementaries to the brightness of each of the above secondary hues, we reach in all cases the figure 81·9, which is nearly twenty per cent. less than the assumed brightness of the white paper which represents, in our diagram, the brightness of the white produced by the three primaries taken together. This calculation affords additional proof, were it needed, of the impossibility of representing by pigments, except in the very roughest way, the quantitative effects which are produced by the addition of coloured lights. And we have already seen that the qualitative effects, as to hue, brightness and purity, are not to be represented by pigments, whether they be used alone or in commixture.

It should be remarked in this place that the optical sensation provoked by the brightest white must of necessity be always stronger than that caused by the brightest yellow, sea-green, or pink, or by any other colour, whether simple or compound. In other words, black contrasts more strongly with white than with any colour.

§ 64. We have still to explain the relation between the three fundamental hues or primaries and the various sensations of colour. Young's theory of colour-perception amounts essentially to this, that in each minute elementary part of the retina of the eye there is at least one

set of three different nerve fibrils (whether "cones" or "rods"), each of the three fibrils of a set being specially adapted for the production of its own specific colour-sensation, yet in a less degree of the two others. Thus the receptive structure of the retina as a whole may be said to consist of an immense number of nerve-fibrils of three orders, what we may call red fibrils being particularly acted upon by such long light waves as those in the red, but being also stimulated in a minor degree by the shorter waves in the green, and still less by those in the blue, the green fibrils will respond most actively to green waves, and in some measure also to red and to blue waves; while the blue fibrils will be most excited by blue waves, though not uninfluenced by green and even by red waves. It follows that when all three kinds of nerve-fibrils are equally and simultaneously affected the complex sensation of white is alone produced. Moreover, if one kind, for instance, the red, be more stimulated than the others (which we will assume are affected to an equal degree), we shall get the sensation of red largely mixed with white. This theory is quite compatible with the microscopic structure of the retina, while it receives very strong support from the study of dichromic or other abnormal varieties of colour-vision.

§ 65. In order to give further precision to the theory of three primary colour-sensations now under consideration a couple of illustrative examples may be introduced here. We begin with an example which must be regarded as the most important of all. How can we produce, with two of the three colours at our disposal, a sensation of yellow like that of a small region of the spectrum a little on the E side of the line D? In this yellow of the spectrum the greatest brightness prevails; it lies between the green and the red; it is undoubtedly produced by pure rays, and is not, in its physical origin, a compound. By combining red and green rays by means of overlapping spectra, by rotating radial sectors of red and green painted surfaces, or of red and green

glass, and by Lambert's method of combination (see § 71) we may produce the sensation of yellow. True, the resultant yellow never approaches in brightness and saturation the spectral yellow; it possesses but a moderate brightness and purity even when formed from overlapping spectra, and, when obtained by rotating discs or by Lambert's method, is no better than a yellowish-grey. But these differences are easily explained. For the very bright simple yellow of the spectrum excites powerfully the red and green fibrils of the retina, producing very little effect on the blue, and consequently we get a sensation of great purity and luminosity very little mixed with white. But red light and green light both act to a marked extent upon the blue fibrils, and so produce a good deal of white, which enfeebles the saturation and reduces the purity of the yellow sensation which they primarily cause. With red and green pigments or glasses the immense amount of colour absorbed lowers the luminosity of the resultant hue enormously, and it ceases to be comparable with the yellow of the spectrum which is its brightest part. Even yellow pigments have a much greater proportionate brightness, as explained in § 95, when compared with those of other colours, and so cannot be properly taken as standards of comparison with the compound yellows made as just described. We may add to this explanation the further fact that a peculiarity of the green rays consists in the impoverishing effect which they produce in all colour-sensations, for they reduce the purity of the resultant hue, apparently adding white light to it. The median position of the green in the spectrum seems to be the cause of this, as it stimulates to a large extent the fibrils which correspond to the less refrangible as well as the more refrangible rays on either side of it.

Our second illustrative example shall deal with the sensation of purple, a non-spectral hue. Experiment shows that it may be produced by combining red with blue or red with violet rays. In either combination the red

and the blue fibrils are excited equally, and the green fibrils very much less; the resultant purple is mixed with a little white, because no one order of fibrils has entirely escaped stimulation. The purple formed by the united action of violet and red rays is brighter than that formed by blue and red rays, because of the rather low luminosity of the greater part of the blue of the spectrum.

§ 66. The following table presents a conspectus of the relations between a large number of colour-sensations and the kind and proportion of nerve-fibrils affected. In order to give an idea, however rough, of the direction in which occur the relative amounts of stimulus imparted in different cases to the three kinds of nerve-fibrils, the names of the latter are printed in capitals of three different sizes, the largest size corresponding to the greatest stimulus.

Colour-sensations.	*Nerve-fibrils Affected.*		
Red	RED	GREEN	BLUE
Orange	RED	GREEN	BLUE
Yellow	RED	GREEN	BLUE
Yellow-green	RED	GREEN	BLUE
Green	RED	GREEN	BLUE
Bluish-green	RED	GREEN	BLUE
Green-blue	RED	GREEN	BLUE
Turquoise	RED	GREEN	BLUE
Blue	RED	GREEN	BLUE
Violet	RED	GREEN	BLUE
Purple	RED	GREEN	BLUE
Purplish-crimson	RED	GREEN	BLUE
White (full)	RED	GREEN	BLUE
Grey (medium)	RED	GREEN	BLUE

§ 67. The selection of red, green and blue or violet as the fundamental triad of colour-sensations has not passed unchallenged since its first full enunciation in 1802–1807 by the illustrious Young. Indeed, for a long time it was hardly recognised, and then became displaced by the theory known as Sir David Brewster's, in which the triad consists of red, yellow, and blue; this last is the

theory generally adopted by artists and writers on art. It will be discussed in Chapter VII. The theory of Rosenstiehl (1881) differs from that of Young and Maxwell in the hues and spectral positions of the three fundamental colour-sensations adopted. These are compared in the following table:—

Maxwell.		Rosenstiehl.	
Red .	$\frac{1}{3}$ from C towards D	Orange	$\frac{3}{4}$ from C towards D
Green .	$\frac{1}{4}$,, E ,, F	Yellow-green	$\frac{3}{4}$,, D ,, E
Blue .	$\frac{1}{2}$,, F ,, G	Blue	$\frac{1}{3}$,, F ,, G

The first and second of these alterations by Rosenstiehl are in our opinion decidedly disadvantageous.

Roechlin has more recently (1886) propounded the view that yellow and blue are the only two simple colours of the spectrum, the third being always found fused with the yellow or with the blue to form the reds and the violets. He asserts that purple may be produced by combining violet and yellow as well as by the union of red and blue.

Hering's hypothesis differs totally from that of Young. The retina is assumed to be furnished with three visual substances, and the fundamental sensations correspond to an assimilation or disassimilation process in one of these. His fundamental visual sensations consist of three pairs—black, white; red, green; blue, yellow.

Kühne (1877-9) supposes that the waves of light produce in the retina certain compounds which give rise to the several sensations of colour. The curious sensitive substance known as "the visual purple," whose existence was first discovered by F. Boll, lends a measure of support to the suggestion of Kühne.

§ 68. It is certain that the vast majority of persons experience, when viewing coloured lights or coloured objects, identical colour-sensations. They will arrange and classify tints and shades of all distinct hues in the same order and in the same groups. Such mistakes as

they will make will be attributable either to imperfect training and inexperience, or to a slight lack of sensitiveness to colours of very small brightness, or to faulty nomenclature. There is, then, a normal, or standard, colour-sensation. But there are numerous cases of abnormal or imperfect colour-vision, ranging considerably in degree, and varying occasionally in kind: they occur much more frequently in men than in women. This subject was investigated by Dr. John Dalton, and subsequently by Dr. G. Wilson, of Edinburgh. Maxwell made a series of instructive experiments upon one of his pupils, who was partially colour-blind. In France, during 1873-5, Dr. Favre found that over 9 per cent. of the railway officials of all ranks (1,050 in number) whom he examined were colour-blind. Prof. Holmgren, in 1876, ascertained the percentage to be nearly 5 amongst the officials (266) of the Upsala-Gefle line in Sweden. Mr. F. Galton found amongst the visitors to the International Health Exhibition in London, of 1884, that out of many hundreds of persons examined, a very large number of males and a very small number of females had a more or less imperfect vision as to distinctions of colour, the numbers corresponding pretty nearly to the percentages which previous observers had found.

§ 69. Colour-blindness, or imperfect and abnormal colour-perception (sometimes called Daltonism), varies in kind as well as in degree. By far the most common defect is a more or less imperfect sensation of red. To persons having this defect the solar spectrum appears to present various tones of two hues, which they call yellow and blue. The dark or chocolate red which for the normal eye begins at the less refrangible end, is to them invisible, while they regard the red, orange, yellow, and pure green regions as various tones of a hue which they name yellow. Near the line F, they perceive a zone of a neutral and pale grey, which to normal vision is a rather turquoise greenish-blue. Beyond this region they perceive tones of one hue, namely, blue. These

appearances may be explained with a fair degree of completeness, by assuming that this variety of abnormal vision is essentially dichromic. The nerve fibrils which in the normal retina receive the sensation of red are not, indeed, wanting, but transmit to the brain the same sensation as that transmitted by the second set of fibrils, the green. The third set of fibrils, the blue, probably do not differ much, if at all, from those in the normal eye. The result of this duplication in this kind of dichromic vision of the nerve fibrils producing the sensation of green is twofold. It not only causes red and green waves to produce the same sensation, but it occasions the curious band of greyish light which occupies the greenish-blue region of the spectrum. For in this abnormal colour-vision two sensations, those of green and blue, suffice to produce white, though a white of low luminosity. Indeed, Maxwell found that he could match, for colour-blind persons, with a white disc, a black disc, and *two* coloured discs, all the tones and hues which they recognised in the solar spectrum.

Colour-blind persons, of the large group we have been describing, discern no difference of hue, but only a difference of tone, between the flowers of a scarlet geranium and its leaves; between red and green cloth; between a gravel path, a grassy lawn, and autumn leaves. They will sort skeins of variously coloured wools in the strangest way, interposing red and yellows amongst the green hues, and mingling blues and violets together. There is, however, a very simple way in which it is possible for such persons to correct in a measure such erroneous impressions. When they are in doubt as to whether they are choosing a piece of scarlet cloth as a match for a piece of green, they have but to view both through a piece of green glass, or through a piece of rich red glass. The scarlet cloth will seem to them nearly black, and the green cloth green through the green glass, while through the red glass the green cloth will appear nearly black and the red cloth ~~green.~~ red

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§ 70. Instances of other varieties of defective colour-perception have been recorded, but they are by no means common. Some persons seem to have the power of perceiving red and blue only, calling the yellow and the green of the spectrum red. And there are a few cases on record in which all sensation of variety of hue in the spectrum was wanting, differences of tone or brightness being alone recognised. It is possible by artificial means to induce temporary and partial colour-blindness. The compound organic principle, called santonine, if taken internally, renders the eye insensible to the violet end of the spectrum; or if red spectacles be worn for some hours, the eyes can still perceive, when they are removed, green, blue, and their compounds, but are insensible to red, both alone and in compounds, the red nerve fibrils having become too completely fatigued to respond to their exciting vibrations.

One unexpected result of dichromic or imperfect colour-vision is the very curious one that persons suffering from this defect enjoy the faculty of discriminating between certain hues which to the normal eye appear identical. In one case examined by the writer, two green solutions, which were of identical hue to ordinary trichromic vision, were at once recognised as different. These solutions were a neutral solution of nickel-chloride and an acidulated solution of copper-chloride. In each case the green colour was complex in constitution. To normal vision all the chromatic constituents acting together produced with both liquids the visual effect of green. To dichromic vision, one at least of the constituents of the light transmitted by one of the solutions was not normally perceived, and hence the two solutions appeared to differ in hue.

CHAPTER VII.

BREWSTER'S TRIAD OF THREE PRIMARY COLOURS, OR THE RED-YELLOW-BLUE THEORY — SECONDARY COLOURS—TERTIARY COLOURS—MIXTURES OF COLOURED LIGHTS—MIXTURES OF COLOURED PIGMENTS—COLOURS MIXED BY ROTATION.

§ 71 In an old and widely-prevalent theory of colour it was assumed that there were three primary colours,—red, yellow, and blue—and that by mixing these in various proportions all other hues could be produced. Sir David Brewster not only lent the sanction of his great scientific authority to these assumptions, but developed them into an elaborate theory which has met, until recent years, with very general acceptance. Artists and physicists alike have regarded Brewster's explanation of the results of the mixture of colours as correct, and the theory of Young was forgotten or ignored. Yet Brewster's view of the existence of three overlapping coloured tracts in the spectrum is one that is incompatible with the simple character and definite refrangibility of every ray in the spectrum, with the entirely subjective character of the sensation of light, and with the simplest experimental tests of its truth which can be applied.

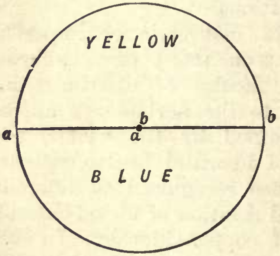

Fig. 16.

One of these tests is so easily made that it may be introduced here. Take two of Maxwell's cardboard discs, each with a radial slit, one of the discs being painted with ultramarine and the other with pale (not orange) chrome-yellow. Adjust the discs so that half of one

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disc is concealed behind the other—as shown in Fig. 16, where *a-a* indicates the radius at which the blue disc passes under the yellow disc, and *b-b* the radius where the yellow disc passes under the blue; on rotating the compound disc, so that the eye shall receive simultaneously blue and yellow light, not the slightest approach to green is produced, but a grey slightly tinged with yellow. By carefully reducing and adjusting the portion of the yellow disc exposed it is possible to get rid of this yellowness, and to obtain an absolutely neutral grey. So in this case, at least, Brewster's theory does not hold good, for the mixture of blue and yellow lights should produce green. Another mode of testing the truth of this theory is of still simpler execution, and is shown in Fig. 17. On a piece of black velvet, placed upon a table, lay a square of blue paper and a square of yellow paper, about a foot apart. Hold a piece of thin plate glass at a convenient distance above and between the squares. By looking through the glass the image of the farther square will be seen directly, that of the nearer by reflection. By raising or lowering the eye, by slightly tilting the glass from the vertical position, or by moving the papers more asunder or closer together, it is possible to reduce or strengthen either image, so that the compound image on the retina shall appear whitish, but certainly not green. This method of combining two colours was devised by Lambert. By these two methods of experimenting, which may, of course, be tried with various blue and yellow

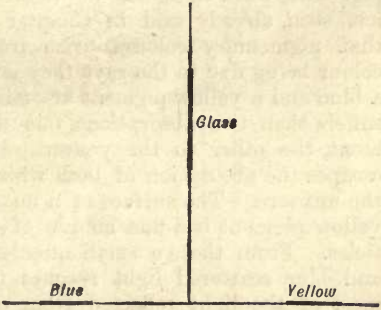

Fig. 17.

pigments, we can never obtain green. The light reflected from a blue pigment, mingled with the light reflected from a yellow, invariably produces white of small brightness, that is, a neutral grey. If, on the other hand, we use the brighter beams of two solar spectra, and receive the yellow of one spectrum and the blue of the other upon the same surface, we get white light, not green.

§ 72. But if blue and yellow lights do not, when mingled, produce green, how is it that blue and yellow pigments, when mingled, do produce green? From what has been already said in Chapter III. we have learnt that pigmentary colours arise from absorption, their colour being due to the rays they do not absorb. When a blue and a yellow pigment are mixed the incident light suffers then two absorptions, one due to the blue pigment, the other to the yellow. It is the light which escapes the absorption of both which gives its colour to the mixture. The surface of a mixture of a blue with a yellow pigment is a fine mosaic of yellow and blue particles. From these a small quantity of mingled yellow and blue scattered light reaches the eye directly, but most of the light reflected from one kind of particles plunges to some small depth amongst the other kind, and loses thereby every ray which the other cannot reflect. Thus, blue light from Prussian blue loses nearly everything but the green of which it always possesses a share, while the yellow light from gamboge loses nearly everything but the green of which it likewise possesses a share; the only coloured light which both sets of particles are competent to reflect is consequently green, hence the green hue of the mixture. This green results, therefore, not from the mingling of blue with yellow light, for both have been almost entirely absorbed, but from the residual light which has escaped absorption amongst both kinds of particles, which light is green. In further confirmation of the soundness of this explanation we may cite the case of mixtures of such blue and yellow pigments as reflect unusually small proportions of green light. If the

above explanation be correct we should expect such mixtures to yield a very poor and dull green. It is well known to artists that the purest blue, true ultramarine, when mixed with one of the purest yellows, yellow (not orange) cadmium, produces, in spite of the brightness of its constituents, a very dull green. On making an analysis, by means of the prism, of the coloured light reflected from each of the constituent pigments, we shall find that in spite of their greater brightness neither ultramarine nor cadmium-yellow furnishes so much green light as Prussian blue and gamboge; in consequence, as we should expect, the hue afforded by their commixture contains much grey and but little green.

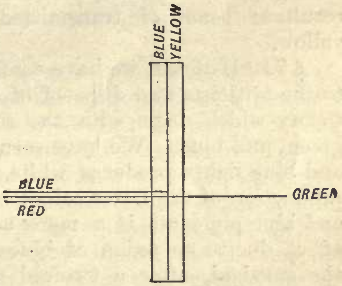

Fig. 18.

§ 73. The true relation of yellow, green, and blue to each other is so important, and yet appears so hard of realisation by those persons who have been accustomed to accept Brewster's theory, that it may be useful to enforce it by still further illustration. The result of associating a transparent blue medium with a transparent yellow one is usually the production of a green colour. This occurs with slips of most kinds of blue and yellow glass or stained gelatine, white light passing through the combination losing by absorption all its coloured constituents save the green, the only hue to which both the glasses or gelatines are transparent. Fig. 18 illustrates the production of green in this way. This explanation is identical with that above given in the case of mixed pigments, except that in the present example the light is transmitted, not reflected. Moreover, this explanation is abundantly confirmed by the prismatic

analysis of the transparent materials employed. But it is possible to find a blue transparent substance, and also a yellow, which, taken together, transmit little but red and green light. Lord Rayleigh selected a film of gelatine stained with litmus for the blue element, and a similar film stained with aurine for the yellow element of a combination. Litmus is opaque to the yellow and orange rays, aurine is opaque to the blue and violet; both are transparent to the groups of rays which we may class as red and green respectively. These rays pass through the combined blue and yellow films, and the resultant beam of transmitted light is a fair orange yellow.

§ 74. Hitherto we have confined our attention chiefly to the criticism and disproof of that part of Brewster's theory which deals with the relations between yellow, green, and blue. We have seen that the union of yellow and blue lights produces white, not green, and that the production of the latter colour by the mixture of yellow and blue pigments is a mere accidental and subsidiary effect, due to no union of blue and yellow light, but to the survival, after a twofold absorption, of the green light which both pigments or coloured media do, in a measure, reflect or transmit. The results of other colour-unions on Brewster's theory accord in the main with those of Young's theory and of properly-conducted experiment, red with blue giving purple, and yellow with red, orange. But here it is necessary to recall the fact that Young's theory does not assume the existence of three primary colours, but of three primary colour-sensations; a very important distinction. To take a single illustrative example, let us cite the case of the union of yellow with red producing orange. Light which we call yellow exists in many spectra as a ray of definite wave-length, and therefore of simple undecomposable constitution; it may also be formed as a sensation by the simultaneous action on the retina of red and green waves. Add red in different proportions to either kind of yellow,

and we obtain identical hues of orange, identical to the eye, though by the prism we find that one set of these orange hues contains chromatic elements which differ from those of the other set. This, then, indicates a notable difference between the two rival theories of colour.

§ 75. We have spoken of Brewster's three primary colours, but something must be said of his secondary and tertiary hues. The secondary colours are three in number—

Orange = Yellow + Red.
Green = Yellow + Blue.
Purple = Red + Blue.

The tertiary colours are supposed to be formed by the union of the three primaries in proportions different to those required to form white. But in reality tertiary hues are impossible. The tertiaries described by Chevreul, Hay, Field, Redgrave and a host of other writers on colour in its relations to art and industry, are nothing more than the dulled tones or broken tones of their so-called primary and secondary colours, for a moment's consideration will suffice to show that neither by the union of three primary coloured lights, nor by the mixture of three pigments of primary hues, can a colour be produced in which all three primaries co-exist as such. Nor can a secondary colour be united with a primary so as to produce a tertiary hue. The resultant hue in no case can exhibit the colour-effect, or, as we should rather say, produce the colour-sensation, of more than two of the primaries taken together. An examination of the supposed constitution, on Brewster's theory, of the so-called tertiaries will explain this point. We will adopt, for equivalent proportions of the primaries, the symbols R for red, Y for yellow, and B for blue; Gy shall stand for grey. We will, moreover, assume that we are dealing with pigments producing their colours by absorption, for the theory was founded, as we have explained already, upon the results of mixing pigments. We may, then,

express the constitution of the six normal tertiaries thus:—

$$\begin{array}{lll} 2Y + R + B = Y + Gy & & = \text{Yellow-grey, or } \textit{Citrine.} \\ 2Y + 2R + B = Y + R + Gy & & = \text{Orange-grey, or } \textit{Buff.} \\ Y + 2R + B = R + Gy & & = \text{Red-grey, or } \textit{Russet.} \\ Y + 2R + 2B = R + B + Gy & & = \text{Purple-grey, or } \textit{Plum.} \\ Y + R + 2B = B + Gy & & = \text{Blue-grey, or } \textit{Slate.} \\ 2Y + R + 2B = Y + B + Gy & & = \text{Green-grey, or } \textit{Sage.} \end{array}$$

Of course in these equations we are adopting the erroneous assumptions of the red-yellow-blue theory; but, even on that theory, according to which equivalents of the three primaries neutralise one another (producing neutral grey or else white), it is impossible for any so-called tertiary hue to present more than two of its constituents to the eye, the third will always have been neutralised by the equivalent quantity of the other two which are present. Take a particular case. It is assumed that a mixture of the two secondary colours, orange and green, gives rise to a tertiary colour known as *citrine.* This hue is really nothing more than a yellow-grey, for its orange constituent contains yellow and red, and its green constituent yellow and blue. Subtracting equivalents of the three primaries so as to form grey, we have nothing but a residue of the primary yellow to produce the whole colour-effect of the mixture of the two secondaries, orange and green. This residual yellow is dulled by the presence of the grey, which is the product of mixing equivalents of pigments representing the three primaries. The colour complementary to citrine or yellow-grey is purple-grey or *plum*, which supplies the blue and red which have been extinguished in the former hue. Of course, throughout this explanation, we have been using the language of the advocates of the red-yellow-blue theory, although, as we have pointed out, it is in many respects erroneous. Nevertheless, though the so-called tertiary colours have not the nature assigned to them, they are of great value both in decorative or ornamental and in pictorial art, and we shall have much to say about

them under their proper designation of "broken" or dulled tones.

§ 76. There is one essential difference in the results of mixing coloured lights (illustrated by Fig. 16) from the results of mixing coloured pigments. In the former mixtures the resultant hues have the added brightness or luminosity of their constituents: in the latter mixtures the resultant hues have the lowered brightness due to twofold or manifold absorption. When green and blue lights are mingled on the retina, the eye receives the combined brightness of both; when green and blue pigments are mingled the eye receives only that portion of the incident light which has escaped the absorptive action of both the green and the blue pigments. In the former case it is brighter than either of its constituents, in the latter it is duller than either, being largely mixed with the grey due to absorption. When two pigments are mixed by means of rotating discs, we have a mixture of coloured lights. And though the resultant hue can possess only a moderate degree of brightness it yet escapes the increased absorption of light due to the inter-action of the material particles when two pigments are mechanically commingled. Some extremely interesting experiments were made by Rood, in order to determine the real differences in constitution between the colours obtained by mixing pigments on the palette, and those which are produced when discs painted in separate sectors with the same pigments are rotated in Maxwell's apparatus. Rood used five pigments only, for his "Hooker's Green" is nothing but a mixture of gamboge and Prussian blue. The Maxwell discs employed in the nine experiments on colours mixed by rotation were equally partitioned between the two pigments; the proportions of the same pigments used for producing colours by commixture on the palette were also equal. The names assigned to the various hues produced by rotation or on the palette must be understood to be only approximately descriptive. The discs were divided into

one hundred degrees; the figures in the table represent percentages :—

EFFECTS OF MIXING PIGMENTS BY ROTATION AND ON THE PALETTE.

Pigments used.	*Colour by Rotation.*	*Colour on Palette.*	*Pigments required to produce by rotation the palette colours.*
50 Violet carmine 50 Hooker's green	Yellow-grey	Brown	21 Violet carmine 22·5 Hooker's green 4 Vermilion 52·5 Black
50 Violet carmine 50 Gamboge	Pale yellow-grey	Sepia-grey	54 Violet carmine 20 Gamboge 26 Black
50 Violet carmine 50 Green (Gamb. & Pruss. blue)	Greenish-grey	Grey	50 Violet carmine 18 Hook. green 32 Black
50 Violet carmine 50 Prussian blue	Blue-grey	Blue-grey	47 Violet carmine 49 Prussian blue 4 Black
50 Violet carmine 50 Carmine	Pink-purple	Dull red-purple	36 Violet carmine 37 Carmine 8 Ultramarine 19 Black
50 Gamboge 50 Prussian blue	Pale greenish-grey	Full blue-green	12 Gamboge 42 Prussian blue 41 Hook. green 5 Black
50 Vermilion 50 Ultramarine	Red-purple	Dull violet-purple	20 Vermilion 20 Ultramarine 51 Black 9 White
50 Hooker's green 50 Carmine	Yellowish-flesh	Brick-red	23·5 Hook. green 8 Carmine 52·5 Vermilion 16 Black
50 Green (Gamb. & Pruss. blue) 50 Carmine	Pale reddish-flesh	Dull dark red	50 Carmine 24 Hook. green 26 Black

The results in the above table are amply sufficient to show how great a stride towards blackness is frequently made when pigments are mixed together. In one instance, the first in the list, shown in Fig. 19, no less than 52·5 per cent. of black had to be added to the

rotating disc in order to make its hue match the extremely dull brown made by mixing violet carmine and Hooker's green. Artists constantly notice the very marked dulness and muddiness of the hues obtained by mixing pigments, and they frequently and wisely have recourse to the mixture of coloured lights by placing small dots and touches of pigments so close together that

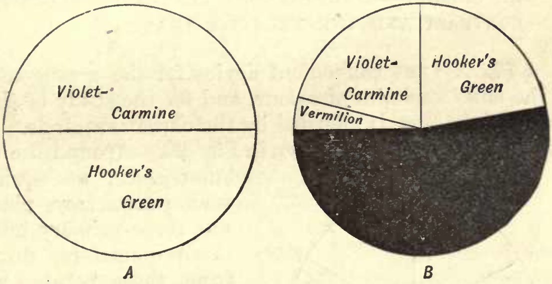

Fig. 19.—The colour produced by rotating the A disc was a yellow-grey: the same pigments mixed on the palette gave a brown which needed, for its production by rotation, the additions of black and vermilion shown in B above.

the colours they reflect mingle on the retina. To this stippling of bright colours, as a fine mosaic work, must be attributed in great measure the luminous and sumptuous effect of many works of Samuel Palmer, William Hunt, and J. F. Lewis. Another important conclusion to be drawn from this table of Rood's is the frequent impossibility of reproducing, without the aid of a foreign element, by the true process of mixing the coloured lights reflected by the pigments, the exact hue of the palette mixture.

CHAPTER VIII.

THE CHROMATIC CIRCLE—COLOURS OF PIGMENTS—THE LAWS OF CONTRAST—CONTRASTS OF TONE—CONTRASTS OF COLOUR—SIMULTANEOUS CONTRAST—SUCCESSIVE CONTRAST AND THE NEGATIVE IMAGE.

§ 77. A VERY convenient device for the arrangement of the chief varieties of colour, and for the study of their mutual relations, is afforded by the chromatic circle. In its simplest form it is shown in Fig. 20. Around the circumference, at equidistant points, are placed the three primary hues; three diameters, drawn from these points, will touch the circumference where the respective complementaries will be found. White is assumed to occur at the centre. Between the circumference and the centre will be found various hues in which the complementaries do not balance or neutralise one another, but one or other exists in excess. Thus along the diameter RED—*Blue-green* we shall discover in succession those hues in which red preponderates, then white will occur, and then those hues in which blue-green preponderates. But the simplest form of the chromatic circle has several defects. It is based upon the assumption that *equal* quantities of any two complementaries produce white, and it further assumes that there are equal intervals in the colour series between the six hues embraced in the figure. If we

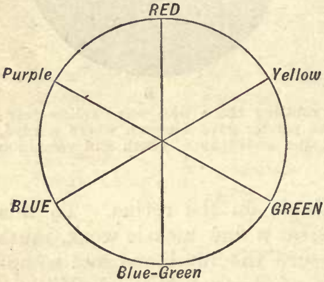

Fig. 20.

waive the obligation to rectify the former defect as being of minor practical importance, the angular distances from each other of the several hues on the circumference can be corrected by means of direct experiment. In the case of pigment-colours, to which we purpose almost exclusively to confine our attention at present, we may select certain pigments of decided hues representing the

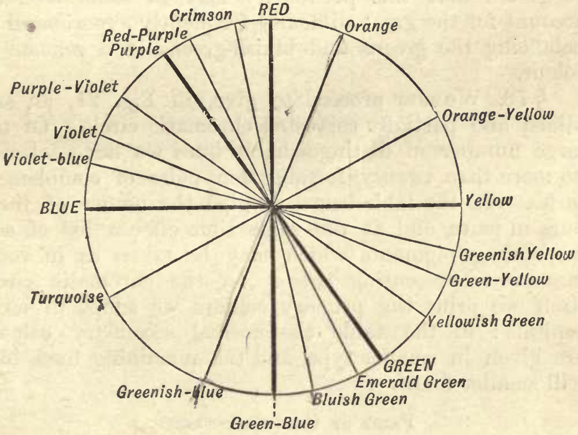

Fig. 21.

chief colours, ascertain the position in a normal spectrum of the colours they severally present to the eye, and then determine the wave-lengths of those colour rays, and so fix their angular position. The results are by no means absolute, partly owing to difficulties inherent in all work of this kind with pigments, but the approximations we reach will be found very serviceable in studying the questions of complementary colours and of colour-contrasts. One of the most important deductions is that very considerable difference of wave-length, and consequently of angular position amongst the various hues

between green-blue and blue, is not accompanied by a difference in colour-sensation corresponding to that which occurs amongst the hues of equal intervals between orange and purple. From this it follows that a difference between two bluish-greens hardly perceptible to the eye demands a difference between their complementaries which seems quite disproportionately large. It has been suggested that this peculiarity may in some measure account for the great difficulty frequently experienced in balancing the greens and bluish-greens in a scheme of colour.

§ 78. We now proceed to give, in Fig. 21, an amplified and partially corrected chromatic circle. Of the large number of distinguishable hues we have selected no more than twenty, forming ten pairs of complementaries. In the table below we give the names of these hues in pairs, and at the same time offer a list of corresponding pigments which may be taken as in some measure representing them. In the chromatic circle itself we print the primary colours we adopt in large capitals: in the table the normal secondary colours are given in smaller type, and the remaining hues in a still smaller fount.

Pairs of Complementaries.

RED	Madder-red or crimson-vermilion.
GREEN-BLUE .	Viridian, the emerald oxide of chromium, with a little cobalt.
ORANGE	Cadmium-yellow, of full orange hue.
GREENISH-BLUE .	Cobalt-green, the "Vert de Cobalt."
ORANGE-YELLOW .	Cadmium-yellow, or deep chrome.
TURQUOISE . . .	Cœruleum, or cobalt-blue with a little emerald green.
YELLOW . .	Lemon-yellow, pale chrome or aureolin.
BLUE	Ultramarine from lapis-lazuli.
GREENISH-YELLOW	Aureolin with a little viridian.
VIOLET-BLUE . .	French ultramarine.
GREEN-YELLOW .	Lemon-yellow with some emerald-green.
VIOLET	French ultramarine with madder-carmine.
YELLOWISH-GREEN	Lemon-yellow with much emerald-green.
PURPLISH-VIOLET.	Madder-carmine with French ultramarine.

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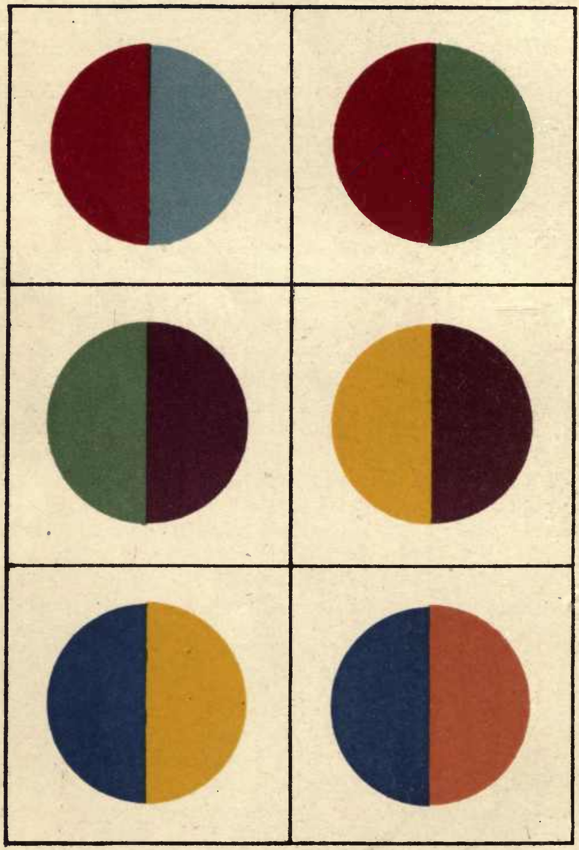

True and False Complementaries Contrasted.
Fig. 22. (see page 93.)

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PAIRS OF COMPLEMENTARIES.

{ GREEN . . .	Emerald-green with a little lemon-yellow.
{ PURPLE . . .	Madder-carmine, some French ultramarine.
{ EMERALD-GREEN .	Emerald-green alone.
{ REDDISH-PURPLE .	Madder-carmine with a little F. ultramarine.

Whether the above pigments are used or any others, such as cobalt-blue, Prussian blue, Indian yellow and carmine, there will always be a difficulty in securing, not merely the proper relationship between the two colours of each pair but the exact or standard hues required both in regard to their colours and their tones. Some aid may be drawn from the observation of the complementary colours of polarised light; but it would be far better if the student could have easy access to a standard set of complementary colours executed in enamels. There would be little difficulty in producing a large number of such sets, which might be suspended in all public libraries, schools of art, and picture-galleries, if not in all school-rooms. We offer, in Fig. 22, a comparison of the three chief pairs of complementary colours according to the theories of Young and of Brewster. It will probably be conceded that the three pairs of compound discs shown on the left of the diagram offer more complete and satisfactory contrasts than those (Brewster's) on the right. If the pigments used had corresponded more closely to the normal hues the effects would have appeared still better.

§ 79. Before proceeding further with the description of the uses of our chromatic circle, especially in relation to pigments, it will be advisable to recur to a subject already noticed in § 63. Strictly speaking, the relative amount of brightness, that is, luminosity, in each of the two colours in a pair of complementaries must be considered. For with red and blue-green the brightness of the latter must have the brightness both of blue and green if it is to form white with its true equivalent of red. Thus a dark blue-green is not the perfect complementary of a bright red. When we are dealing with

coloured lights this conclusion is obvious, and we find that the blue-green made by uniting blue and green lights is much brighter than the red with which it unites to form white light. With pigments the case is otherwise, and so the only way in which, in a diagram or figure, we can make a blue-green pigment approximately neutralise a red pigment is to add a certain amount of white to the former; in other words, to use a pale tint of it. The same is true of the pair, purple and green, and of the pair, yellow and blue. In the last-named case there is no difficulty in achieving the desired brilliancy of the yellow, for yellow pigments are characterised by quite exceptional brightness; with purple the case is so different that we are obliged to dilute or weaken this compound hue until it corresponds to a kind of pink, a pink a little bluer than rose-madder. This colour is very near that of the rose-acacia, or of almond blossom, or of the flowers of the double peach; it is perhaps more closely represented by the flame of burning cyanogen. With the six other pairs of complementaries in the circle the difference in brightness between the two colours will be less, for in each case the total brightness is shared more equally as each colour is a compound one. Thus in the pair—violet and yellow-green—the violet has the brightness of the full or normal blue with a portion (say about one-third) of the brightness of the full red, while the yellow-green has the brightness of the full green with the remainder of the brightness (say two-thirds) of the full red. Assuming unity to represent the brightness of each one of the three primaries, we shall have this equation representing the apportionment of the total brightness:—

$$\left.\begin{array}{ll} \text{Violet,} & 1{\cdot}33 \\ +\ \text{Yellow-green,} & 1{\cdot}67 \end{array}\right\} = \text{White, } 3.$$

§ 80. We now pass on to consider the constitution of those hues which contain grey. They may be considered as primary and secondary colours of low

luminosity mingled with white; when speaking of pigments we regard them as containing both black and white. We have explained how, from an erroneous notion as to their constitution, they came to be called "tertiaries." These constitute "broken" hues, and are the dulled tones of the primaries and secondaries. It is not easy to name them in a way which will prove generally acceptable, but the following list, in which the order of the chromatic circle is followed, may prove of some service :—

a.	Broken red	=	*Maroon.*
	Broken orange	=	*Russet.*
	Broken orange-yellow	=	*Brown.*
b.	Broken yellow	=	*Citrine.*
c.	Broken yellow-green	=	*Olive.*
d.	Broken green	=	*Sage.*
a.	Broken blue-green	=	*Bluish-sage.*
b.	Broken blue	=	*Slate.*
c.	Broken violet	=	*Lavender.*
d.	Broken purple	=	*Plum.*

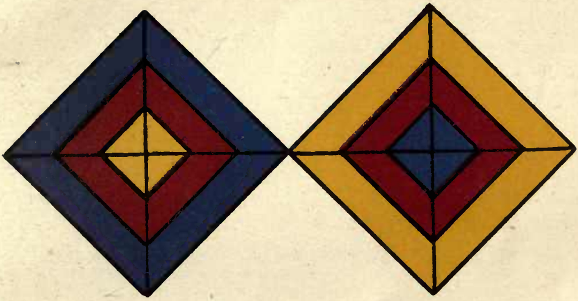
Pairs of complementary broken hues are indicated by prefixed italic initials : the complementary of russet is a rather bluish sage-colour; of brown, a very bluish sage.

Colours are often spoken of as either retiring or advancing, as either cold or warm. These distinctions, though in part founded upon the association of particular hues with distant and near objects or with cold or warmth, are susceptible of explanation, in some measure, by means of physiological and physical considerations. Thus the warm colours, which are found in our chromatic circle between the greenish-yellow and the reddish-purple, represent more than two-thirds of the brightness or luminosity of the whole of the chromatic elements of white light, although the proportion of the area they occupy does not exceed one-third. Again, in the case of advancing colours, such as yellow, orange and red, they occur at that part of the spectrum where the rays are less refracted, and are at the same time highly luminous.

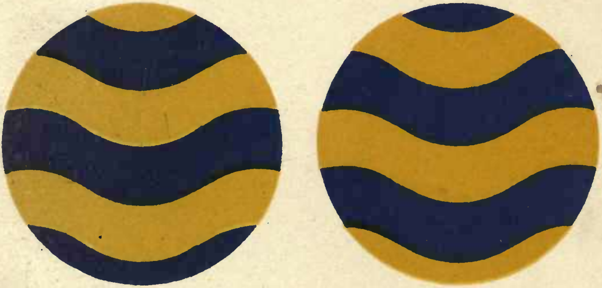
The Fig. 23 illustrates some of the curious optical effects produced by different dispositions of some of the chief of these so-called advancing and retiring colours.

§ 81. Complementary colours of full brightness and purity afford the most striking examples of the effect called contrast. When each of a pair of such colours differs as much as possible from its fellow in hue, but is of the same degree of brightness, it is found, while the brightness of both is enhanced, that the hue of both is unchanged by the close neighbourhood or contiguity of the two colours. But if the pair be not truly complementary, or if in brightness or purity one colour differ from the other, then such difference will not be seen exactly as it is, but such dissimilarity as exists, whether it be of one hue, of purity, or of brightness, will be enhanced by juxtaposition. This is the primary law of contrast, which embraces three varieties dependent respectively upon differences as to the three constants of colour, namely, purity, brightness, and hue. If two adjacent colours differ in brightness, that which is the more luminous will increase in brightness, while the less luminous will have its brightness diminished. If two adjacent colours differ in hue such difference will be increased, each hue tending to change as if it had been mixed with the complementary of the other. In the case of complementaries no increase of difference in hue is, however, possible.

§ 82. Contrast caused by difference in brightness is commonly called contrast of tone. This kind of contrast may occur alone or it may be associated with contrast of hue and contrast of purity. It will be well to consider first the simplest cases, in which contrast of tone is unaccompanied by other contrasts. But it is impossible to reduce experiments on tone-contrast to their simplest expressions. A third element always comes in, namely, the background on which the pair of tones is placed for examination. Whether this background be black, white, grey, or coloured, it must necessarily differ in some



Advancing and Retiring Colours.
Fig. 23. (see page 96.)



Lustre Produced in Binocular Vision.
Fig 29. (see page 107.)

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one direction from one or from both the trial pieces, and will therefore itself produce a contrast. To minimise the complication thus introduced we may try our first experiment for producing the phenomena of tone-contrast in three ways, using three backgrounds with identical trial pieces on each. We first take two strips of pale grey paper, A and A′ in Fig. 24, and place them a few inches apart on a large sheet of paper in a good light. We then prepare two similar strips of a considerably darker shade of grey, B and B′, and place them, as shown in the figure, one alongside of A and the other the same distance from B as A′ is from A. Upon steadily looking

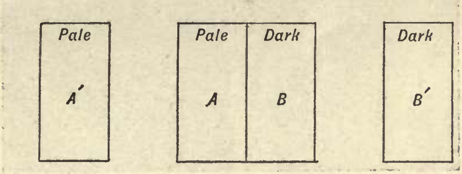

Fig. 24.

at the four strips for a short time it will be seen that A close to B appears lighter than A′, which lies at some distance, while B appears correspondingly darker than B′. The effect of contrast in enhancing differences of tone may be further studied thus :—Make such openings, five in number, in a piece of card, as will serve to divide each of the stripes A and B into three portions. When viewed through this card, held between the trial pieces and the eye, it will be found that the two contiguous portions of the strips are most contrasted in tone, and the others less so in proportion to their distance from the line of contact. The experiment should now be repeated with a background of black velvet, and again with a background of grey paper lighter in tone than either of the strips. But the effect of contrast of tone is still better seen when a series of toned strips is placed in contiguity. In such a case the effect on all the strips save the end ones is that of

double contrast. For the second strip or second tone has one side of it made apparently darker by reason of the contiguity of the lighter tone of strip, while the other side seems lighter, owing to the contiguity of the darker tone of strip 3. The general results of these double contrasts is that the whole series or scale of tones presents the appearance of a number of hollows, although, in fact, the apparent hollows or concavities are perfectly flat areas of uniform shade. The effect of this experiment is approximately represented in Fig. 25, where the real flatness of each tone of the six may be verified by covering up all

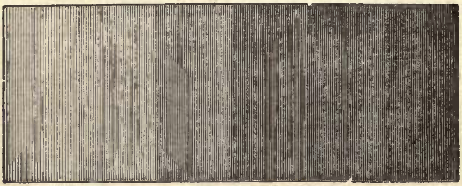

Fig. 25.

the others by a card. This diagram of contrast of tone may be made in a more effective way by dividing a strip of cardboard into several equal sections—say six—by faint pencil lines, and then giving all six a light uniform wash of Indian ink. When this is dry five sections receive a second similar wash. Afterwards the same operation is repeated until the third section has received three washes, the fourth four, the fifth five, and the sixth section six. In carrying out this process, all sections, except those which are being tinted, should be hid from view, for without this precaution it is difficult to secure the perfect flatness of each tint. If a series of pieces of grey paper, of the same hue but of different tones, is obtainable, it may be used in the construction of the same figure. The pieces should be of the same size, and should be pasted close together on a slip of cardboard; strips of grey glass or gelatine may also be used in such a way as

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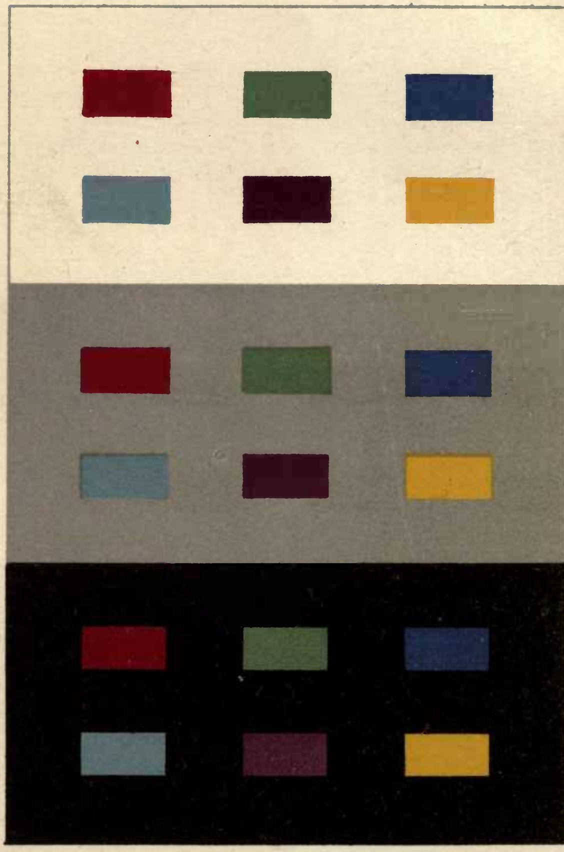

Contrast of Colours with White, Grey, & Black.
Fig. 26. (see pages 99. & 117.)

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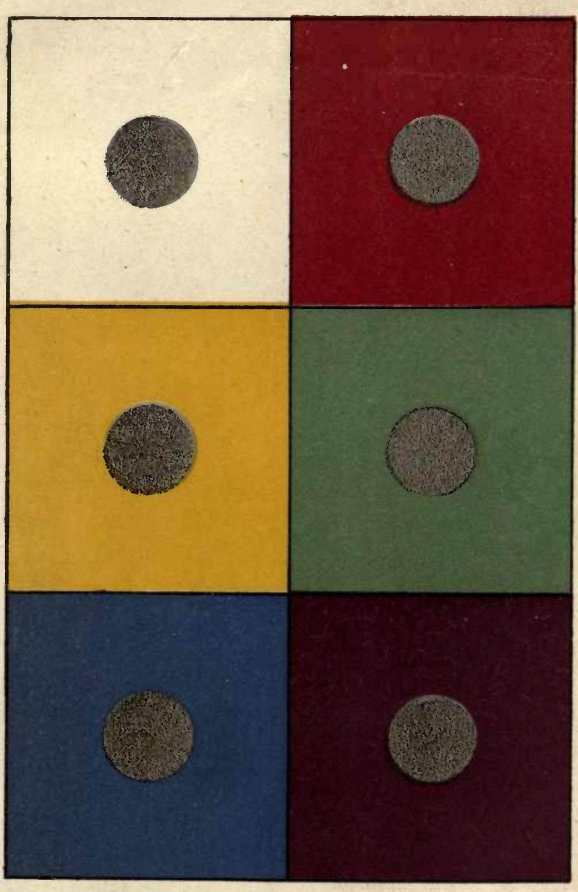

Simultaneous Contrast.
Fig. 27. (see page 100.)

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to present at one end one thickness of the material and at the other end six or more thicknesses. It is scarcely necessary to state that the tones of any one colour may be employed, instead of grey, to illustrate this kind of simultaneous contrast, but its characteristic effect is not seen unless the contrasting tones differ considerably in intensity, increase by regular gradations and are in close contiguity or absolute contact. If tones of a colour, whether tints or shades, be used, there is generally, however, a complication introduced, owing to the difficulty of getting a series of such tones which shall be identical in hue (see Chapter iii., § 28).

It is evident that the phenomenon of simultaneous contrast of tone largely affects the chiaroscuro of all drawings in black and white and in monochrome. An example is afforded in the case of a drawing in Indian ink, where light touches will be observed to enrich pale washes at the same time that dark touches serve to relieve the heaviness of dark washes.

§ 83. The simplest instances of simultaneous contrast of colour are afforded by the contiguity or contact of a single colour with black, grey, or white. The coloured illustration (Fig. 26) shows how very differently the same normal and full hue of red, of yellow, of green, of blue and of violet appears to the eye when it is seen on colourless grounds of different degrees of brightness. All colours seem brighter on a black ground and darker on a white ground: the effect of a grey ground depends upon the relations subsisting between the tone of the grey and the tones of the several colours. With the grey used in our diagram the yellow alone is much affected, the change being in the direction of an apparent increase of brightness. The alterations suffered by various colours in contact with neutral grounds may be best studied by means of coloured strips or discs of paper of rather small size placed upon rather large surfaces of white, grey, or black paper, and viewed in a moderately bright light. Such experiments should always be

supplemented by a converse series, in which discs or strips of white, grey, and black paper are placed upon self-coloured grounds. In the latter series we often obtain very marked examples of simultaneous contrast. The brightness of a white ground is, however, so much greater than that of most pigmentary colours placed upon it, and the brightness of black so much less, that in neither case do we fulfil the exact conditions necessary for obtaining the full effect of simultaneous contrast of hue. What we need for this purpose is a very moderate and not fatiguing luminosity of the neutral element in the combination. Pure black paper does not send enough light to the eye to stimulate that part of the retina on which its image falls, white paper (which reflects at least twenty-five times more light than black paper) sends too much. A dark grey tint answers well. In the diagram (Fig. 27) we notice that the grey disc, which is really identical in every respect in all six sections, appears tinctured with bluish-green on the red ground, with blue on the yellow ground, with purple on the green ground, with green on the purple ground, and with yellow on the blue ground.

To avoid the effect of adjacent colours the diagram should be inspected through a card having an opening just large enough to allow one only of its six divisions to be visible at the same time. In obedience to the law of contrast of colour enunciated in § 81, we shall find that each of the grey discs is tinged with colour which is complementary to that of the ground on which it is placed. The same result is observed when black figures are printed on coloured grounds, but in that case the arrangement should be viewed through a thin piece of white tissue paper. With grey discs on coloured grounds the complementary colour produced is strongest in the case of red, orange, and yellow grounds, where the grey disc is rather darker than these in tone; the reverse is true with green, blue, violet, and purple grounds.

§ 84. We will now consider the rather more complex

case of the association of two colours. In order to avoid the introduction of a third element, either of tone or colour, we will dispense with backgrounds by placing a small coloured disc or square upon a large surface of another colour. Two colours not far removed in hue may be employed in the first experiment. Upon a ground of turquoise blue place a square of paper painted with French ultramarine; repeat the colours but reverse the arrangement, and let the two combinations be viewed in a medium light. The ultramarine on the turquoise ground will incline still more than before towards violet,

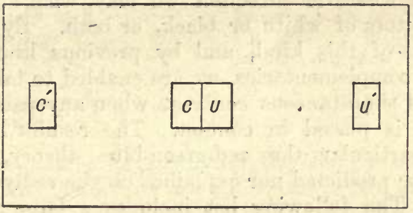

Fig. 28.

while the turquoise on the ultramarine ground will acquire a still more greenish tinge than it had before. Each acquires something more of the complementary of the other, they become more different in hue than they were before. If, also, one be purer (freer from white) than the other it will become still purer while the less pure hue will become still less pure. In the special example before us the turquoise will become paler, and the ultramarine deeper or more saturated. Simultaneous contrast in all such cases of course affects the large area as well as the small, but it is usually difficult to detect it on an extensive surface except where it touches the smaller piece of paper of different hue. For this reason we duplicate the experiment as described above. The usual way of trying this experiment involves a background of white, grey, or black, the coloured strips being

placed on colourless paper, as shown on Fig. 28, where C and C′ are the cœruleum strips, and U U′ those painted with ultramarine; C′ and U′ are affected in tone only by the ground, while C and U suffer the change of hue previously described owing to their contact.

§ 85. The changes in the apparent hues of pairs of colours in juxtaposition due to simultaneous contrast can be studied not only by means of the colour-arrangement described in the preceding section, but by the use of Maxwell's rotating discs, which have the advantage of enabling us to adjust the brightness and purity of the comparison-hues, in whatever direction we may wish, by adding radial sectors of white or black, or both. By direct experiments of this kind, and by previous knowledge of the true complementaries, we are enabled to tabulate the results of simultaneous contrast when any pair of differing hues is placed in contact. The results confirm in every particular the red-green-blue theory, and can neither be predicted nor explained on the red-yellow-blue theory. The following list includes a large number of the most important cases of such contrasts:—

Pairs of Colours.	*Change due to Simultaneous Contrast.*
RED with	inclines to purple.
ORANGE	„ yellow.
RED with	„ purple.
YELLOW	„ green.
RED with	becomes more brilliant.
BLUE-GREEN	„ brilliant.
RED with	inclines to orange.
BLUE	„ green.
RED with	„ orange.
VIOLET	„ blue.
RED with	„ orange.
PURPLE	„ blue.
ORANGE with	„ red.
YELLOW	„ green.
ORANGE with	„ red.
GREEN	„ blue-green.
ORANGE-YELLOW with	becomes more brilliant.
TURQUOISE	„ brilliant.

Pairs of Colours.	*Change due to Simultaneous Contrast.*
ORANGE with	inclines to yellow.
VIOLET	,, blue.
ORANGE with	,, yellow.
PURPLE	,, blue.
YELLOW with	,, orange.
GREEN	,, blue-green.
YELLOW with	,, orange.
TURQUOISE	,, blue.
YELLOW with	becomes more brilliant.
BLUE	,, brilliant.
GREEN with	inclines to yellow-green.
BLUE	,, violet.
GREEN with	,, yellow-green.
VIOLET	,, purple.
GREEN with	becomes more brilliant.
PURPLE	,, brilliant.
BLUE with	inclines to green.
VIOLET	,, purple.
VIOLET with	,, blue.
PURPLE	,, red.

It must not be imagined that the changes enumerated in the above table are at all equal to one another in amount. We have, indeed, always some change, but it varies much in the case of different pairs. When the chromatic interval (on the colour-circle) is small then the change of *hue*, in virtue of simultaneous contrast, is large; when the interval is large the change of hue is slight, but it is accompanied by change of brightness: when the interval is as large as possible there is no change of hue, but the brightness of both hues is increased.

§ 86. Successive contrast may be observed when we tire one set of retinal fibrils by gazing for some time on a surface of very decided colour and brightness. Afterwards, on looking at a colourless surface of white, grey, or black, it will be found to be tinctured with the complementary of the first colour. Thus, if a piece of paper painted with vermilion be first stared at the nerve fibrils which respond to the red waves of light will be much more fatigued than those which respond to green and

blue light by the continuous call on their perception of red, and, in consequence, any surface afterwards looked at will appear to be tinctured with the complementary of red, namely, blue-green. Even if the second surface viewed be coloured, its proper colour will be affected by the occurrence of this "negative image" due to successive contrast. Looking at a series of pieces of the same scarlet cloth in succession the last piece will appear less saturated than the first, for its hue will be mingled with its complementary bluish-green. But the eye may be rested and its power of appreciating red may be restored by gazing upon a bluish-green surface for some time. One mode of producing the phenomenon of successive contrast consists in placing a square of paper of decided colour and marked with a central black spot upon a sheet of grey paper, and attentively regarding the black spot for twenty or thirty seconds. The piece of coloured paper which we will assume to be green is then suddenly withdrawn, by pulling a thread previously attached to it: a pink or pale-purple after-image will be observed to occupy the space before occupied by the green square. This phenomenon may be thus explained. The green light from this square has fatigued the green nerve-fibrils of the retina to a much greater extent than the red or blue fibrils. When, therefore, the light of low luminosity from the grey paper reaches the eye (after the removal of the green square) its green element meets with little or no response from the green fibrils, while, on the other hand, the unimpaired sensibility of the blue and red fibrils of the retina responds perfectly to the corresponding rays of the reflected light, and produces a resultant image of mixed red and blue hues, that is, a pink or purple. It is unnecessary to describe in detail the colour-phenomena produced by this kind of successive contrast, for they can be predicted by means of a knowledge of complementary colours such as is afforded by our chromatic circle (Fig. 21).

The following cases of successive contrast may be

specially noted as involving considerations not wholly embraced by the law of complementary colours. If the eye has attentively regarded a series of pieces of paper or cloth coloured red, but having a rather low degree of luminosity (or mingled with some black), the subsequent view of bright red paper or cloth will result in very slight alteration of its hue or tone, as the red nerve-fibrils will not have been sufficiently tired to allow of the production of the complementary after-image. They may, however, be just so slightly fatigued as to render the bright red last seen rather less brilliant than it would otherwise have been. Reverse the experiment, and look at dark red after having seen bright red, and then successive contrast occurs. So also a black (or grey) square on scarlet paper, if suddenly withdrawn after twenty seconds spent in observing it, gives a successive contrast-image of the square, which appears of an intense red on a dull red ground, because the part of the retina previously occupied by the image of the black square is perfectly fresh and completely attuned to the perception of red, while the other portions of the retina have their red fibrils tired out for the time.

§ 87. The table included in § 85 will serve to show the directions in which the hues of colours apparently change when the eye has first seen one colour and then looks at another. Thus, if the eye has first seen red and then looks at yellow, the latter inclines towards greenish-yellow, acquiring, as in the case of simultaneous contrast, a hue tinctured with the complementary of that first seen. Another mode of observing such phenomena involves the successive and separate use of each eye. Close the right eye and then look steadily with the left at a sheet of *red* paper. When the red appears rather duller than at first, owing to the special sort of fatigue it induces in the retina, look immediately, still with the left eye, on a sheet of *purple* paper. This, receiving the complementary of red, namely, bluish-green, will appear bluer than before, in fact, a kind of violet. To verify this observation

it is only necessary, after having closed the left eye, to open the right, and to look with it on the sheet of purple paper. The purple will be perceived differently now, and so far from inclining towards violet will actually appear modified in the contrary direction, becoming redder instead of more bluish. These experiments require some care and several repetitions, and will sometimes fail, because different individuals possess very different powers of appreciating slight variations in hue, and of recording their impressions. One eye, also, will not infrequently be found to differ from its fellow in many important particulars.

§ 88. When one colour is presented to one eye and another colour is simultaneously presented to the other, some curious phenomena occur. If a sheet of paper, painted with ultramarine, is viewed with the right eye at the same time that a similar surface of lemon-yellow is seen by the right eye, we get a fluctuating effect, sometimes, though rarely, seeing a grey-white produced by the union of these two complementaries, sometimes seeing both colours at once, as if one were shining through the other; added to this there is a lustrous or polished appearance of the surfaces which is quite unlike any phenomenon to which we have already drawn attention in these pages. If an arrangement be prepared (of the form usually adopted for stereoscope slides), consisting of two discs, one disc having a series of wave-bands of cobalt-blue, alternating with bands of rather pale viridian, the other, intended for the other eye, being made up of a reversed series of bands of rather pale viridian and cobalt-blue, we shall see, on viewing the two figures in the stereoscope, the several phenomena above-described, sometimes the blue and the green uniting into sea-green and sometimes remaining for a few seconds separate. There will also be the same lustrous appearance as of the shimmer of waves on a summer sea. It is probable that phenomena of this kind, due to binocular vision, occur very frequently in nature; they are, of course, incapable

of direct reproduction by the art of the painter in whose work the same hues are seen by both eyes. Fig. 29 (facing p. 96) shows the mode in which the colours (in this case, blue and yellow) are to be distributed in the arrangement above described.

§ 89. There is one remarkable case of simultaneous contrast to which no reference has yet been made. If the same object, in a darkened room, be made to cast two shadows, owing to the presence of two lights, the shadows will differ in colour if the lights so differ. The shadow of a rod cast by candle-light, when viewed side by side with the same shadow as cast by daylight, appears blue, the complementary colour to that of the yellowish light on either side of it: the shadow cast by daylight will then take on a greyish-yellow tinge, owing to simultaneous contrast. Phenomena of this order constantly occur in nature where shadows, cast by two sources of light of different hue, will be found to have acquired complementary hues; so, too, a beam of daylight, finding its way into a room illuminated by the orange-yellow light of candle-flames will acquire a bluish tinge.

CHAPTER IX.

PERSISTENCE OF RETINAL IMPRESSIONS—IRRADIATION—THE COLOUR OF THE LENS OF THE EYE—PARTIAL AND GENERAL VISUAL FATIGUE—THE DEVELOPMENT AND CULTIVATION OF THE SENSE OF COLOUR.

§ 90. After the eye has seen a coloured object for a few seconds it retains for a time the original impression correct in colour, but (at least after the lapse of about one-fiftieth of a second) reduced in force; this is the positive image. Then succeeds a second or negative image of the object, tinctured more or less strongly

with a hue complementary to that of the original. The duration of each image depends upon the brightness, the hue, and the length of time the original object has been viewed. By making a small circular aperture near the edge of a large black disc capable of rapid rotation and properly adjusted against a rather smaller circular opening in the shutter of a darkened room, we may determine with some degree of accuracy the duration of images which differ in luminosity and hue. Glasses of different colours may be placed in the opening of the disc and the number of revolutions of the disc may be recorded. In order that the retinal impression of such a coloured spot should be a continuous ring of light the spot must complete its circular path in about thirteen-hundredths of a second, but the minimum time differs slightly with different colours. A piece of glowing charcoal whirled rapidly at the end of a string in the air affords a familiar example of this persistence of the retinal image. But this effect, in the case of highly luminous bodies, is complicated by another appearance. If a piece of charcoal, no thicker than one's finger, be lighted at one end, and then plunged into oxygen, it will actually appear to swell as the combustion becomes more intense and the light brighter. A spiral of platinum wire, heated to whiteness by a galvanic current, not only has its apparent diameter enormously increased, but the separate turns of the spiral seem to approach, and even to coalesce, if not originally too distant. The crescent of the moon appears, for the same reason, to belong to a much larger sphere than the dimmer remainder of the disc which it clasps. All these are either subjective ocular effects due to what in optical language is called "spherical aberration," or are to be traced to the want of perfect transparency in the humours of the eye—a scattered light, of varying degrees of brightness, always surrounding the definite images of highly-luminous and of strongly illuminated objects upon the retina. The result of this nebulous border about such images is to

increase their apparent size, but it is often imperceptible under the ordinary conditions of moderate illumination. Much of the peculiar indefiniteness and mystery which impart considerable beauty to flames of different kinds, to strongly illuminated clouds and surfaces of water, and to the intense reflected lights of metallic ornaments, is due, in part, at least, to irradiation. Even the coloured borders which surround the edges of coloured objects may be traced to irradiation. A rim of bluish-green light appears by the margin of a red wafer placed on grey or white paper, owing to the extension of the image of the red wafer on the retina beyond its geometrical image. The rim is bluish-green because the image of the nebulous border becomes tinctured with the complementary of red.

§ 91. Another kind of ocular modification of colours is of a quite different kind, and does not occur in the normal and healthy eye. It was shown by Leibreich that the yellow colour which tinges the lens of the eye in advancing years produces remarkable effects upon the appreciation of blue and of bluish colours. This aged condition of the eye is not always strongly marked, but occasionally, as in the case of the painter Mulready, it has produced very curious results. The later pictures of this artist are often spoken of as too cold, too blue, or too purple. If they are examined through a piece of glass tinted of a pale sherry yellow colour they assume a natural appearance, and exhibit the same harmonious and agreeable system of colouring which Mulready adopted in his earlier works. Leibreich pointed out that we have an excellent illustration of how Mulready saw his own works with the naked eye in his later years, if we do but look through a yellow glass at a picture of his, in the South Kensington Museum, called "The Young Brother." Without the interposition of such a glass it is far too blue to be satisfactory; with the glass it closely resembles, in its scheme of chromatic effect, an earlier and more accurately-coloured work by the same hand in the same collection, but painted twenty-one years before, when the

lenses of the artist's eyes were normal. Even when they became yellow the objects of external nature were scarcely modified in hue in consequence of the ocular change, for the yellow medium could cut off but a very small proportion of the blue in the intense light and colour of the day, while the eye, through the constant presence of this yellowness, became less appreciative of yellow, and more appreciative of its complementary, blue. But with pictures the circumstances were entirely different. The light reflected from pigments is so small in quantity and so low in intensity, in comparison with that of external nature, that a yellow lens will seriously interfere with the blues and bluish hues which paints represent—it will very largely intercept them. So the painter will try to set this right by strengthening his blues, and increasing their proportions in his mixed colours. To his yellow lenses his pictures then become right in harmony and key of colour. To a normal lens they are too blue, his reds, too, being changed, becoming purple or violet, and his greens likewise tending towards blue-green. If, then, we look at one of Mulready's later pictures through a sherry-yellow glass, or even through a thick layer of mastic varnish, which in course of time has yellowed, it recovers in a great degree its proper hue, and appears to us as it appeared to him; but if, on the other hand, we look at one of his early pictures through the same media, we see that it is altered in nearly every respect for the worse. No wonder, then, that the artist himself became more and more dissatisfied with his earlier colouring as his lenses grew yellower.

§ 92. We have already explained how subjective colours due to simultaneous and successive contrast arise from partial visual fatigue, certain portions of the retina losing for a time the fulness of their power of perceiving one or other of the three elements of colour. An excessive illumination of white light produces fatigue in all the three sets of nerve-fibrils, red, green, and blue; even the constant strain on the vision caused by a long

examination of drawings in black and white causes something of the same sort of weariness, and so does a day spent in a picture-gallery. In these cases the visual fatigue being general does not produce the subjective chromatic phenomena which has been described in Chapter VIII. But it is of importance as tending to render the eye less appreciative generally of delicate differences in tone and in hue. It is certain that the sensations of light and colour always involve the expenditure of a certain amount of vital energy, and are attended by certain physiological changes. Time is required for the restoration of the organs of vision to their equilibrium. Under ordinary conditions of moderate exercise of the power of appreciating light, shade, and colour the intervals of non-exercise during the day and the hours of sleep at night more than suffice to bring back to their normal condition both the physical apparatus and the nervous sensibility of the eye.

§ 93. Endeavours have been made to show that in olden times the appreciation of colour, as distinct from that of light and shade, was very imperfect. The main argument is founded upon the limited vocabulary for various colours possessed by the oldest writers, and the vague usage of such terms as they employ. But when we examine attentively such ancient works of decorative art in colour as remain to us, particularly those of Eastern origin; when we recognise how our colour language even in the present day fails in fulness and precision; when we find that peoples who are commonly accounted uncultured or savage continually use agreeable colour-combinations which we would fain imitate; when we observe children in the present day habitually noticing none but the most vivid hues; when we discover that a keen sense of colour belongs to many groups of the lower animals, not only to mammals but to birds, fishes, and even insects, then we have very good reasons to doubt that the sense for colour in the human eye and brain is a development of the last few thousand years.

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The experimental proof, obtained by Rood, that the amount of time necessary for vision is the same, namely, one forty-billionth of a second, whether colour or merely light and shade be recognised, tends to show that the human sense for colour is as ancient as the human sense for tone.

§ 94. But it does not admit of doubt that individual sensibility to colour admits of large variations, and that it is susceptible of immense improvement. This cultivation of the sense of colour is, however, rather psychological than physiological, rather mental than physical. It is not that the organ of vision is improved, but our power of interpreting and co-ordinating the sensations which it transmits to the brain. And it is here that the effects of association come most prominently, though often unconsciously, into play. We try to trace out the causes of the vast numbers of colour-sensations which we are continually receiving, but we constantly find that the cold methods of analysis fail to explain the mental appreciation with which we regard the astounding fertility of nature in its gifts of colour. We shall endeavour farther on to demonstrate how greatly our pleasure in colour depends upon an infinitude of most minute variations of tone and hue, which, by their suggestion of the wealth, variety and vastness of nature, and by their association with scenes and circumstances of enjoyment and delight, enrich our appreciation of the sensation of colour in a way which no mere optical demonstration of chromatic phenomena can ever completely trace. Still, experiment and analysis are serviceable tools in the hands of the artist who seeks to reproduce, to modify, or to develop, in tangible form, the happy combinations and arrangements of colour with which his mental recollection is stored. But how rarely do we find even the most strenuous and cultivated painter or colour-designer to be quite free from an occasional crudity or weakness in his use of colour and of tone.

CHAPTER X.

DESCRIPTION OF CERTAIN COLOURS — THE CONTACT AND SEPARATION OF COLOURS — COLOURS WITH WHITE, GREY, AND BLACK — DOUBLE AND TRIPLE COMBINATIONS OF COLOUR—COMPLEX COLOUR-COMBINATIONS—CHROMATIC EQUIVALENTS.

§ 95. THE discussion of colour-combinations may appropriately follow the account which has been given of the very important phenomena of contrast. But as we shall have to deal chiefly with a certain number of hues of very decided character, it may be serviceable to gather under a few headings some descriptive remarks concerning these hues, following so far as may be the order in which the colours succeed one another in the spectrum. We shall thus acquire some knowledge of the chief characteristics of the chromatic elements with which our groupings or assortments are built.

Red. Red, when of low luminosity or mingled with much black, appears of a chocolate hue. The normal red is approximately represented by crimson or Chinese vermilion, or by scarlet vermilion washed over with madder carmine. Madder carmine itself, and ordinary or cochineal carmine, verge slightly upon purple, that is, contain some blue. The normal red is less bright or luminous than yellow, but it is warmer and more retiring. The majority of our red pigments do not correspond so nearly to the normal red as mercuric iodide, which has been called "geranium colour." It is, however, from its fugitive or changeable character, wholly unfitted for use as a paint. If we take a stick of red sealing-wax, which is coloured by vermilion, it will reveal, on examination by the prism, the presence, in the light scattered from its surface, of all the rays from red up to the line D in the

orange-yellow. Even the flame of a burning lithium salt shows an orange element. Red glass coloured by copper sub-oxide does not transmit unmixed red rays, but many orange rays as well. Two or three thicknesses of it do, however, transmit a purer red beam.

Orange. This colour passes, according to its progression towards green, from orange-red to orange-yellow. In brightness its yellower hues come very near to the most luminous and advancing of all the spectral colours, yellow. It is seen in tolerable perfection in the pigment known as cadmium yellow, the sulphide of cadmium, and in the skin of a richly-coloured ripe orange. To make a good bright orange colour by a mixture of pigments it is essential that the yellow pigment used should incline to orange rather than to green, and the red pigment to orange rather than to crimson or purple. If the contrary be the case, and a greenish-yellow pigment be mixed with a red, or a yellow pigment with a red inclining to purple, a large amount of grey is produced by the considerable absorption which takes place—that is, the quenching of several chromatic elements, so that a muddy or dulled tone of orange results. By dilution with white pigments some orange pigments yield hues having a somewhat buff colour.

Yellow. This is the most luminous of all the colours of the solar spectrum, where, however, it occupies an exceedingly narrow space. The brightness of most yellow pigments, such as lemon yellow and chrome yellow, is proportionately much higher than that of red, green, and blue pigments. They reflect to the eye a good deal of the light lying on either side of the yellow, but the resultant visual impression such light produces is that of yellow. All the methods of obtaining yellow from the combination of the light from red and green pigments yield a hue which is disappointing in luminosity, and would be called a greyish-yellow. Some transparent yellow pigments verge towards green in their lighter tints, and towards orange in their deeper tints. Yellow is

regarded as an "advancing" colour. Mixed with grey it yields citrine, with black, dull yellowish-green, or olive.

Green. In the spectrum it will be seen that much of the so-called green light is tinged with yellow, and much towards the more refrangible end, with blue. Yellowish-green is often observed in the budding foliage of trees in spring, bluish-green is not an infrequent hue of the ocean, especially near the shore; it has been called sea-green and aquamarine. Emerald green is not a pure typical green, but contains a decided trace of blue; it reflects more white light than vermilion. Its brightness is not particularly great, but the visual fatigue which it causes is very marked, in fact, all tolerably strong greens tire the green nerve fibrils sooner than reds tire the red fibrils and blues the blue. It is probably on this account that strong greens are often so disagreeable in chromatic combinations, requiring unusual skill to bring them into a pleasant colour scheme. It is cold, too, as well as intense. Green paints mixed with white and black produce sage greens, which are always bluer than the appearance of the green used would lead one to predict.

Blue. Blue acts less strongly upon the retinal nerves than violet, which itself is less energetic than green. It is a retiring and cool colour. Genuine ultramarine from lapis-lazuli is probably the purest blue pigment. Artificial ultramarine generally inclines towards violet, though different preparations of it vary considerably in hue. Cobalt blue reflects much green and violet light. Prussian blue, indigo, and cœruleum contain a good deal of green. On mixing any of the last three pigments with madder carmine, in order to form a violet or purple, a large absorption of light occurs, and a dull or greyish-purple or violet is the result. Blues mixed with white and black produce slate colour.

Purple. There is no sound pigment which exactly represents purple, but a mixture of two of the aniline dyes, magenta and mauve, makes a tolerable representative

of it. Its paler tints are approximately near in hue, but a trifle bluer than the flowers of the peach and the almond. A mixture of genuine ultramarine and madder carmine may be used in painting to represent purple and also violet, the ultramarine being laid on a white ground, and then glazed with the madder pigment. All purples and violets lose much of their blue when viewed by the light of gas or candles, becoming redder and generally duller. Purple belongs to that region of the chromatic circle in which the warm hues are situated, but is much less warm than red. Vermilion and cobalt blue produce by admixture on the palette a very dull purple, owing to the orange in the former pigment and the green in the latter.

§ 96. We may now enter upon the discussion of chromatic combinations. Of these, the simplest consist of two tints, or shades or broken tones of the same hue. If these pass by insensible gradations into one another we have in reality a very complex arrangement, which, from its soft and tender character is, when appropriately used, agreeable to the eye. A useful modification of this arrangement is obtained by tinting a colour into white on the one side, and shading it into black or breaking it with grey on the other. Or we may associate a single pale tint of a colour with a single darkened or dulled tone of the same colour. This arrangement, though constantly useful in pictorial art, produces a certain vague or confusing effect in decorative art, unless the two tones be separated by a line of black, white, or gold. The general and most conspicuous effect of such use of a dividing line or edging of white is an apparent increase of the saturation of both the tones thus separated; black, on the other hand, increases the brightness but diminishes the purity (freedom from white) of both the tones. In the consideration of the specific effects of the association of white, grey, or black with a single colour, we follow the order in which the colours succeed each other in the spectrum, adding purple at the end.

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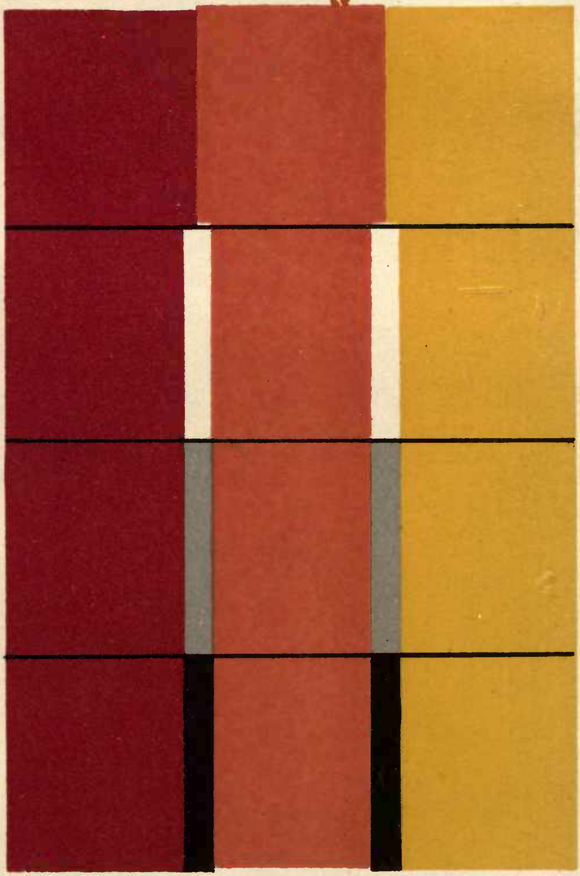

The Separation of Related Hues.
Fig. 30. *(see page 131)*

Vincent Brooks, Day & Son Ltd lith

The coloured diagram (Fig. 26) illustrates some of the observations here recorded.

1. RED.—*Red* with *white* becomes deeper, more saturated or purer, and less bright. The combination, as to intensity of contrast, is similar to that of green with white, being less than that of blue, violet, or purple with white, but more marked than that of orange or yellow with white.

Red with *grey*, when the latter is moderately pale, becomes brighter and less saturated.

Red with *black* becomes brighter and less saturated, sometimes acquiring an orange tinge.

2. ORANGE.—*Orange* with *white* is rendered deeper, and perhaps a trifle more reddish. The contrast of tone between orange and white is much greater than that between yellow and white, the combination is consequently more effective.

Orange with *grey*, when the latter is pale, is deepened and reddened. With dark tones of grey orange becomes lighter.

Orange with *black* becomes brighter and slightly yellower.

3. YELLOW.—*Yellow* with *white* is rendered deeper, less bright, and less advancing, acquiring a slight greenish hue. The lighter the tone of the yellow the less pleasing is the combination.

Yellow with *grey* is rendered brighter and perhaps slightly orange. The combination is satisfactory when the grey is rather dark.

Yellow with *black* is rendered paler, brighter, and more advancing. The combination affords the most intense contrast of tone next to that of white with black. The blackness of the black is modified by acquiring a slight bluish hue which enriches it.

4. GREEN.—*Green* with *white* becomes deeper and purer; the combination is capable of yielding very beautiful effects.

Green with *grey* becomes deeper only when the grey

is pale; if the grey be at all dark it acquires a purplish tinge.

Green with *black* is rendered brighter and paler, while the black suffers, being tinged with a reddish or purplish hue.

5. Blue.—*Blue* with *white* constitutes a generally pleasing combination. The contrast of tone is very decided when the blue is at once pure and bright. The effect of strongly illuminated white clouds in deepening the tone of the blue of the sky bordering them is a good example of one of the chief characteristics of this combination; under such conditions the white often assumes a slightly yellowish tint.

Blue with *grey.* Grey, if pale, deepens and purifies blue; the combination, though necessarily cold, is often most serviceable in pictorial as well as in ornamental art.

Blue with *black.* This combination is less agreeable than that of blue with grey, or of violet with black, especially when the tone of the blue is deep. Light tones of blue are made still paler, but broken tones, more saturated, by contiguity with black.

6. Violet.—*Violet* with *white* affords a strong contrast of tone; the combination is an agreeable one, resembling that of blue with white.

Violet with *grey.* The distinctive hue of violet makes itself felt strongly in this combination, which is a quiet and agreeable one.

Violet with *black* gives but a slight contrast of tone when the violet is pure. The black acquires a rusty brown hue, which reduces its depth.

7. Purple.—*Purple* with *white* affords a good contrast of tone. Pale purples and rosy tints form agreeable combinations with white.

Purple with *grey* resembles in effect the combination of violet with grey; the grey, if of moderate area, becomes decidedly greenish.

Purple with *black* is rarely a satisfactory combination; the black acquires a greenish hue.

§ 97. From what has been said in the preceding paragraphs it will be seen that the general effect of white upon a colour is to increase its purity, to deepen its tone, and to emphasise its hue. Grey varies in its effect according to its depth of tone; black usually increases the brightness but lowers the apparent purity of a colour. But these effects are generally complicated by the changes of hue brought about by chromatic contrast—the black, grey, or white, if small in area, becoming, when associated with a colour, often slightly tinctured with its complementary. A further difficulty in ascertaining the exact effect upon any colour of black, grey, or white arises from the almost necessary introduction of a third chromatic element as a background. For whether we employ a background of the colour itself, or of white, grey, or black, as the case may be, we cause an enormous disproportion in the area of the two associated members when the background is sufficiently extensive to exclude from our purview any other background, as of white paper or of a dark space.

§ 98. When two tints of the same hue are associated there is always an increase in their apparent difference of tone. When two shades, or two broken tones, of the same hue are similarly associated, the same effect is produced. Often, also, there occurs, in each class of these combinations, a chromatic difference. For a pale tint of a colour frequently differs in hue from a deep tint of the same, the effect of contiguity being similar to that of increased or diminished illumination, a light tint of any ordinary blue having a violet cast becoming less violet, and a deep tint of the same colour verging more strongly upon violet. For details concerning changes of hue, reference may be made to § 119. When a broken tone of one colour is associated with a pale or pure tone of the same, the broken tone becomes still more mixed with grey, and often acquires a slight suspicion of the complementary colour; at the same time the pale or the pure tone acquires additional purity.

§ 99. Colours of different hues associated in pairs belong to three categories : those in which the difference in hue is small, those in which it is considerable, and those in which it is as large as possible (the complementaries). Pairs belonging to the first category require special treatment, and will be discussed in § 106, under the heading "the small interval and gradation." We now address ourselves to the subject of dyads or pairs of colours in which the difference of hue is very decided. We cannot consider this matter from a purely scientific point of view, for we are unable in many instances to discover why certain pairs of hues are pleasing, and others unsatisfactory or even offensive. Association, habit, one's surroundings, with other obscure causes, are all factors, unconsciously employed, it may be, in the formation of our judgment. The subject has been investigated by Chevreul, Brücke, Rood, and other experimenters, and we are indebted to their researches for the majority of the opinions gathered into the following tables. An asterisk attached to the name of a colour indicates that the mixture of grey or black with it improves the effect of its association. It may be further remarked that, in many cases where two colours of full depth yield a bad or unsatisfactory assortment, the reduction of the tone of one of them, by a considerable addition of white, often makes the combination agreeable.

Normal red with	violet	bad.
,,	blue	excellent.
,,	blue-green	good, but strong.
,,	green	good, but hard.
,,	green-yellow	fair.
,,	yellow*	unpleasing.
Scarlet with	violet	bad.
,,	turquoise	good.
,,	blue	good.
,,	yellow	unpleasing.
Orange-red with	violet	good.
,,	purple	fair.
,,	blue	excellent

Orange-red with	turquoise	good.
,,	blue-green	unpleasing.
,,	yellow-green	fair.
Orange with	purple	bad.
,,	violet	good.
,,	blue	good, but strong.
,,	turquoise	good.
,,	blue-green	good.
,,	green	fair.
Orange-yellow with	purple	good.
,,	violet	excellent.
,,	blue	good.
,,	turquoise	fair.
,,	blue-green	moderate.
,,	green	bad.
Yellow with	violet	excellent.
,,	purple	good.
,,	normal red	poor.
,,	turquoise	moderate.
,,	blue-green*	bad.
,,	green*	bad.
Greenish-yellow with	purple	good.
,,	violet	excellent.
,,	scarlet	strong and hard.
,,	orange-red	fair.
,,	turquoise	bad.
,,	normal blue	good.
Yellowish-green with	normal red	good, but hard.
,,	purple	difficult.
,,	blue-green	bad.
,,	blue	good.
Normal green with	purple	strong, but hard.
,,	scarlet	difficult.
,,	orange-red	hard.
,,	turquoise	bad.
Blue-green with	purple	fair.
,,	violet	good.
,,	blue	bad.
,,	green	bad.
,,	yellowish-green	bad.
,,	turquoise	bad.

§ 100. The above list comprises fifty-four only of the very numerous combination, in pairs, of some of the

decided hues which we have named and described in preceding chapters. It is assumed that in our experiments on their chromatic effects, pleasing or otherwise, we have been using coloured materials, which neither by any peculiarity of texture, nor quality, nor design, are capable of improving the results. Cloth and paper are suitable; silk, velvet, glass, and enamel, for various reasons, give results which are complicated by the introduction of new elements. Pairs, in these latter materials, in consequence of the presence of lustre, translucency, or "throbbing" hues, in varying degrees, will often become quite acceptable, while in prosaic cloth, or paper, they are just the reverse. For the same reason the colours which we so constantly see happily associated in nature must not be assumed to be always susceptible of successful reproduction in the studio or the workshop. The brightness of natural objects, their soft and infinite gradations of hue and tone, their intricate variations of substance and texture, their beautiful forms and their delightful associations, all unite in producing a complex harmony which generally defies complete analysis. Take as an example the blue of the sky seen amidst the green foliage of a forest tree. This is not a mere crude opposition of blue and yellowish-green. The blue deepens and becomes a more decided blue from the horizon towards the zenith; the leaf-green is deeper than the blue, but is not one hue, but many hues. One leaf, or a part thereof, will reveal the fact that the light it transmits is coloured differently from the light it reflects. One leaf, or a part, will be brightly illuminated by much white, grey, or bluish light, from the clouds or the sky; another will show its proper hue and tone; another will exhibit a deep shadow. One leaf will have its contour wholly dark, or partly dark and partly light; and then will have its surface exquisitely toned from pale to deep green. Add to all these enrichments the variations introduced by means of the forms and groupings of individual leaves, to say nothing about stems and branches, and it becomes evident that green

foliage against a blue sky is not to be reproduced or represented by a piece of green paper laid upon a piece of blue paper. Yet such analysis as we have attempted to make above, of the constitution of this natural contrast, may teach us how to amend our first crude impression as to its nature. We may separate our pair of hues by outlines of white, or grey, or gold; we may make one hue paler than the other; we may cause both to palpitate with minute variations of tone and of hue.

§ 101. The dyads, or pairs of colours described in our list, do not comprise many of those intermediate hues and dulled or broken hues of which ornamental art constantly makes such admirable use. No mention has been made of garnet-red, salmon-pink, and rose-grey; of amber, straw, fawn, and citron; of lavender, lilac, plum, and puce. All of these hues, to adopt the conventional terms we have previously explained, are to be regarded as compounded of two primaries, in proportions other than in which these elements occur in the so-called secondary colours, or in those hues for which we have found a place in our chromatic circle; all, or nearly all of them, also contain some grey. There are two methods by which we may construct pairs, into which these hues shall enter. The simpler of these methods consists in preparing a large number of these rarer hues by means of strips of paper painted with water-colours, or by means of a large selection of what are known in the shops of fancy stationers as "surface-papers." These strips are arranged and re-arranged in twos, with or without separating lines of black, grey, white, or gold, until agreeable combinations are obtained. The other method, which has a more limited range of usefulness, involves the use of Maxwell's rotating discs. If, for instance, we want to learn what kind of pale blue will yield the strongest possible contrast with a certain deep amber colour, which we desire to employ in this association, we take discs of amber, white, blue, and green, and mount them together on the axis. Then by means of

the radial slits in the discs, we adjust them all so, as to obtain, on rotation, a neutral grey. Then we note the relative areas of the white, green, and blue sectors used, withdraw the amber sector and replace it with an equal grey sector of proper tone. On rotating this compound disc, we obtain a pale greyish-turquoise, which is the exact complementary of the amber. In this example, as in all others, we have the opportunity of ascertaining approximately beforehand what colours the several discs must possess, by referring to the chromatic circle and its pairs of complementaries.

§ 102. And here it will be well to state that every hue has in fact an immense number of complementaries. Yellow is complementary to blue, but you may mingle the yellow, or the blue, or both, with white, with grey, or with black, and yet the mixtures will be complementary. The use of such modified complementaries is often far preferable to that of hues in which both brightness and purity are at their highest available maximum point. Nor, indeed, must it be supposed that pairs of colours exhibit their highest beauty when they are complementary; the large interval on the chromatic circle, say at least of 80°, more often of 90°, or above, yields very many beautiful pairs. Colours differing by a smaller interval than this generally suffer by harmful contrast which causes the hues to look dull and poor, while a considerably greater difference than this produces, in many cases, too strong and crude a combination by the excess of helpful contrast which a near approach to the complementaries brings into action. The merits of the small interval, as we shall presently show, rest upon a different basis. That contrasts may be too complete, and may be, in consequence of their strength, trying and hard, is exemplified by three pairs:

Black with white; green with purple; red with blue-green.

The first pair is distinguished by the highest possible difference of tone; the other pairs by a very moderate

difference of tone, but the largest difference of hue; they need the greatest judgment in their mode of employment if they are to be introduced into ornamental work. For reasons which it is difficult to formulate, the strong colour contrast, yellow with blue, is much more easily managed; but in this case there is a great difference of brightness in the pair; an approximately equal brightness in a pair of strongly contrasted colours is generally unpleasant.

§ 103. The study of triple colour combinations is surrounded with peculiar difficulties, the moment we leave the triads in which two hues are associated with white, grey, or black only. Perhaps, however, a few words concerning these latter triads may help in clearing the way. Thus, if we wish to separate and emphasise two nearly related colours, such as deep violet and deep blue, both of which are cool and retiring, black will prove to be much inferior for this purpose to white. Deep tones of violet and blue approach so closely in their measure of brightness, to black, that the latter effects little towards their separation, while it is itself injured by contact with them, acquiring a rusty hue. But white, on the other hand, though it deepens these colours, renders them purer, and, by acquiring a faint tinge of their complementaries, yellow or orange (in obedience to the law of simultaneous contrast), causes their differences to appear more distinctly. Still, there is a triple combination, which is slightly preferable to that of blue, white, violet; it is formed by the substitution of grey for white. The contrast of tone becomes less violent, and the whole effect is undoubtedly more agreeable.

§ 104. Many pairs of hues forming agreeable combinations are injured by the addition of a third hue, but all the poor and bad dyads may by this means be improved. Thus, while greenish-yellow with normal blue forms a good pair, and the addition of violet spoils it, it will be found that violet improves the effect of the pair, greenish-yellow and greenish-blue. Generally speaking, good triads may be arranged by taking three colours

which are situated from 90° to 140° or 150° apart on the chromatic circle. It is, however, well to remember that, as a rule, two of the hues should belong to the "warm" group, for triads in which two of the colours are "cold" are more difficult of management, and are less generally esteemed, though valuable in certain schemes of chromatic decoration. Of the modes of collocating the colours of a triad, and of their relative proportions, we speak in a subsequent chapter, here we merely give a short list of such arrangements, derived partly from experiment, and partly from the study of specimens of decorative art in textiles, in wall-papers and wall-decorations and in pottery.

I.	Normal red. Yellow. Normal blue.	IX.	Terra-cotta. Maroon. Sage-green.
II.	Purple-red. Yellow. Greenish-blue.	X.	Yellow. Violet. Yellowish-green.
III.	Orange. Normal green. Violet.	XI.	Normal green. Orange. Turquoise.
IV.	Orange. Normal green. Purple-violet.	XII.	Amber. Blue (pale). Crimson.
V.	Amber. Cream. Blue (medium depth).	XIII.	Maroon Bronze-yellow. Olive-green (dark).
VI.	Normal red. Gold. Normal blue.	XIV.	Apricot. Crimson. Gold-brown (pale).
VII.	Leaf-green. Puce (deep). Rose-grey.	XV.	Flesh-red. Normal blue. Olive-green (pale).
VIII.	Leaf-green. Violet. Salmon.		

By the addition to these triads of white, grey, or black, or by the introduction of one or more tints, shades, or

broken tones of the fundamental hues, we reach complex colour-combinations which would require a far more elaborate study than we can accord them in this place. But apart from the generally useful addition of a contour or boundary-line, it is not to be imagined that in purely decorative work great complexity and extensive multiplication of hues is commonly advantageous. Directly we are able to use choice and fine materials, such as silk or enamel, which give us what artists call "quality" of colour, we discover that two or three hues are frequently more effective than half-a-dozen. The beautiful sixteenth-century velvets of Italy may be cited as examples of such happy simplicity in combination. By beauty of pattern, by varying depths in the pile, and by contrast of surface and of texture, such simple dyads as yellow-green with medium violet, pale olive-green with deep indigo, leaf-green with deep blue, and pale leaf-green with deep amber, the most beautiful effects are produced. However, it may not prove useless if we cite a few examples of complex colour-combinations (hexads), which are capable of yielding delightful results when their elements are properly collocated, and are used in due proportions.

I.	Full bluish-green	Medium yellowish-olive	Pale orange.
	Full blue	Medium purple ...	Crimson.
II.	Deep blue	Pale green-blue ...	Dark blue-green.
	Dark red	Pale yellow-green	Dark yellowish olive.
III.	Medium crimson	Salmon	Pale yellow.
	Medium yellow-green	Medium yellowish-olive	Marone.
IV.	Deep blue	Pale blue-green ...	Turquoise.
	Maroon	Pale yellow	Orange.

Nos. I. and III. are "warm" combinations; No. IV. will be improved by the introduction of grey of medium depth.

The question as to the relative proportions in which the several colours of the groups named in the present

section should be used admits of many answers according to the circumstances of each case, and to the nature of the coloured materials employed. But it is generally found that when three or more colours are brought into close proximity one of them must be made more prominent than the rest, so as to form the characteristic feature of the group. The prominence may be brought about by giving to the selected hue either a larger area, or an increased degree of brightness or of purity ; it may even be attained, in some instances, by the employment of one of the colours in spaces of more striking form, or more conspicuous position than those assigned to the remainder. The happy effect often produced by the introduction of a third element, however unobtrusive, into a pair of colours affords an illustration of the value of a minor constituent in a group. And just as two similar trees in a picture appear awkward, but become beautiful by the introduction of a third of smaller or larger size, and just as we should never feel satisfied with a cathedral having its central tower and its two western towers of the same height, so we find that a group of colours gains greatly in beauty when it includes a dominant member. It may be safely affirmed that there is always something unsatisfying, if not unpleasant, in associations of two or more colours when they are of nearly equal tone, however correct, in a purely chromatic sense, the combination. The due co-ordination and subordination of tones in all colour-arrangements is, indeed, only second in importance to the due adjustment of hues. However, when three or more colours having equal tone-values are associated, we seem to feel the unpleasantness of the contest for mastery amongst them to a lesser degree than when two equal-toned colours only are brought into contact.

§ 105. We now approach a subject which has often been treated dogmatically—the doctrine of chromatic equivalents. It has been argued that as certain colours in certain proportions produce white, all the chromatic elements of a composition should be so adjusted that

complete neutralisation should be achieved, and, consequently, that if all the constituent hues were mingled on the retina no excess of any hue or hues should be detected. Such a result is rarely possible, and would not necessarily be agreeable. Almost every satisfactory colour-combination, whether pictorial or ornamental, is characterised by a dominant hue—generally of yellow, orange, or red. It is probable that this preponderance of warm colours, although in some way related to their agreeable associations, is mainly dependent upon the fact that yellow, orange, and red exhaust the nervous power of the eye much less than blue, violet, and green. In fact, if we pursue the problem further, we shall find that the optical balance of a colour-scheme differs from the physiological balance and that again from the æsthetic. It is, however, obvious that, whatever use we may choose to make of them, the determination of chromatic equivalents is quite feasible. Whether we deal with the coloured lights of the solar spectrum, or with those transmitted through coloured glass, or with those reflected from pigments or coloured surfaces of any kind, we may ascertain in what proportions they must be mingled on the retina in order to produce white or a neutral grey. Our experiments will naturally be made with pigments, and here we once more have recourse to Maxwell's rotating sector-discs. In an experiment with a compound disc, made up of sectors of vermilion, emerald green, and artificial ultramarine, the areas of these three pigments necessary to yield on rotation a neutral grey equalled the following percentages:—Red $= 36\frac{1}{2}$; green $= 33\frac{3}{4}$; blue $= 29\frac{3}{4}$. Thus with these pigments, approximately representing the hues of the three primaries, the chromatic equivalents may be roughly put down as—

Red = 12; Green = 11; Blue = 10.

Field, by an entirely faulty method, arguing with the false data of the red, yellow, blue hypothesis, gave five as the chromatic equivalent of red and eight as that

of blue; to yellow, he assigned the value three, asserting that a neutral grey would be the result of mingling these hues in the above-named equivalents. Put to the test of actual experiment with rotating discs, the assertion is completely falsified, for neither in these proportions nor in any similar, can these three colours be made to yield a neutral grey. Of course, by mixing these pigments on the palette, a neutral grey may be formed, but this, as we have previously shown (§ 76), is a complex case of absorption, and in no way represents the mingling of the hues of a chromatic composition which takes place on the retina of the eye. It should be added here that were we in possession of three pigments, all of *equal* brightness or luminosity, but having the exact hues of vermilion, emerald green, and artificial ultramarine, we should have to use very different proportions of them to achieve a neutral grey, namely, red, forty-four; green, seventy-four; blue, ten; for the luminosity of emerald green is much higher, and that of ultramarine very much lower, than that of vermilion.

CHAPTER XI.

THE SMALL INTERVAL AND GRADATED COLOURS—HARMONIES OF ANALOGY—HARMONIES OF CONTRAST—HARMONIES OF SERIATION—HARMONIES OF CHANGE—INTERCHANGE AND COUNTERCHANGE OF COLOUR—DISTRIBUTION, BALANCE, AND QUALITY OF COLOUR—THROBBING COLOURS—DECORATIVE AND PICTORIAL COLOUR—COLOUR, AS MODIFIED BY PAINTING MEDIA AND VARNISHES, BY GROUNDS AND BY BRUSH-WORK.

§ 106. If we select a small region of the solar spectrum, such as that which includes the hues between orange-red on the one hand, and pure yellow on the

other, we shall observe an imperceptible gradation, or passage, of one colour to another. This gradation, often erroneously called "shading," has a delicate beauty of its own, and furnishes a chromatic arrangement which may often be advantageously employed, both in decoration and painting. But in a large number of instances we desire to deal with isolated hues, and to suppress a large number of the *passage* colours. By means of an opaque diaphragm, having a number of vertical slits, we may easily separate half-a-dozen of the spectral hues lying between orange-red and yellow, thus obtaining such a gradated series as this:—

1. Orange-red.
2. Reddish-orange.
3. Orange.
4. Yellowish-orange.
5. Orange-yellow.
6. Yellow.

If we employ all these hues in one colour-scheme, we shall find ourselves almost compelled to employ them in the spectral order, and thus to produce the effect of gradation. For if we put the extremes, orange-red and yellow, side by side, then it will be impossible to deal satisfactorily with those colours which differ less in hue than these, for their smaller difference will be reduced, if not annulled, by the greater contrast between the pair, orange-red and yellow, and the optical effect will be confusing. A less satisfactory combination is obtained by associating three only of the group together, so as to secure a rather larger interval between them. Thus, we may use orange-red, orange, and orange-yellow, or reddish-orange, yellowish-orange, and yellow, or red, orange, and yellow. Here, however, the immense value of the introduction of a separating line of black, grey, or white (shown in Fig. 30) is felt. For, while we accept the small interval and gradation as representing the change of hue consequent upon diminution, or increase of brightness, directly this association of ideas is precluded by the imperfection of the series, or by the jumps from one hue to another being too large, then we demand some new

element in the combination which shall be competent to accentuate the differences of hue which do exist. The value of the neutrals, black, grey, and white, and, under certain circumstances, of gold, for this purpose, has been already studied. We shall direct attention, later on in the present chapter, to several ornamental arrangements of colours in which use is made of this means of separating and emphasising groups of related colours, but there can be no doubt that for pictorial effect the value of pure gradation of hue cannot be too highly esteemed. In nature, such gradations abound, and the really great artist, when he perceives and reproduces them in his works, succeeds in suggesting the variety, the tenderness and the mystery of nature. But there are two kinds of colour gradation constantly met with in the external world. In the one we have a succession of tones of the same colour, or of closely related colours, arranged in orderly sequence; in the other kind the same tones are so collocated in such contiguous patches as to mingle, sometimes completely, sometimes imperfectly, upon the retina of the eye, thus producing a sort of palpitating colour, in which first one chromatic element and then another appears to assert itself. In painting, this effect may often be reproduced by scumbling, or dragging one colour over another, as in skies, where a grey-blue, a pale blue, and a greenish-blue may in this manner be so associated as to give the appearance of space and atmosphere. Even the texture of the paper or canvas tends to produce effects of this order.

§ 107. Before proceeding with the discussion of the various kinds of colour-harmonies, it may be of service if we are able to offer a basis for their classification. Chevreul's arrangement of these harmonies, which has been generally adopted, includes all the species under two groups, called respectively "Harmonies of Analogy" and "Harmonies of Contrast."

I.—Harmonies of Analogy.

1. *The Harmony of Analogy of Scale.*—This harmony is essentially that of a series, the harmony of gradation. It includes those cases in which is presented a simultaneous view of three or more tones of the same scale, whether these tones be tints or shades or broken tones. It is obtained in various degrees of perfection, according to the number of tones present, and the value of the intervals between them. When the tones are not easily separable by the eye, and pass into one another, then the effect called "shading" is produced.

2. *The Harmony of Analogy of Tones.*—When two or more tones of the same depth, or of nearly the same depth, but belonging to different but related or neighbouring scales, are viewed together, the harmony of tone is produced. Many such assortments are, however, displeasing to the educated eye, unless the tones be so selected as to fall into a series with a gradually increasing quantity of some one of their colour-elements, when they may be ranged in the third kind of harmonies of analogy.

3. *The Harmonies of a Dominant Hue.*—An example of this harmony is afforded by viewing a contrasted colour-assortment, a bouquet of flowers, or even a landscape, through a piece of glass so slightly tinctured with a colour as not to obliterate, but merely to modify, the various colours belonging to the arrangement or composition.

II.—Harmonies of Contrast.

1. *The Harmony of Contrast of Scale* is produced by the simultaneous view of two or more distant tones of the same scale.

2. *The Harmony of Contrast of Tones* is produced by the simultaneous view of two or more tones of different depths belonging to neighbouring or related scales.

3. *The Harmony of Contrast of Hue* is produced by the simultaneous view of colours belonging to distant scales, and assorted in accordance with the laws of contrast. This kind of contrast includes also those cases in which the effect is still further enhanced by differences of tone as well as of colour.

The distinction between these two classes or groups of harmonies is somewhat arbitrary, for the collocation of any two tones or any two colours, whether its result be agreeable or otherwise, inevitably involves the element of contrast. Colour-harmonies, so far as contrast is concerned, differ in degree and complexity, but Chevreul's harmonies of analogy pass by steps more or less marked into distinct and undoubted harmonies of contrast. In every harmony there is contrast of tone or of colour, and therefore contrast cannot be employed as a criterion of classification. The two fundamental ideas underlying complex colour harmonies may perhaps be expressed as those of *gradual change* and of *abrupt change.* And instead of separating colour-harmonies into two distinct groups, it would be better to arrange them in order upon the arc of a circle, placing at one extremity those harmonies on which the succession of contiguous tones or hues is marked by the smallest differences, and at the other extremity, those harmonies in which the elements of contrast are most strongly developed. About the middle of the arc will be arranged those transitional harmonies in which contrasts of tone, contrasts of colour, and contrasts of tone and colour combined, begin to make themselves felt as modifying the effect of the regular sequence of tones and related hues. According to this scheme, we may commence with harmonies in which the succession of tones is so gentle as to be barely perceptible, and we may end with those harmonies in which the change of hue and of tone is most abrupt. A list of illustrative examples will help to elucidate the scheme :—

1. The passage, by insensible differences, of the

tints, shades, or broken tones of a single hue, from light to dark.

2. The passage, by small but regular, definite, and perceptible steps, of the tints, shades, or broken tones of a single hue, from light to dark.

3. The passage, as in the preceding example (2), of the tones of one hue from light to dark, when each step is separated by a neutral element, such as white, grey, or black.

4. The passage, by insensible differences, of one hue, or of the tones of one hue into another related hue or its tones.

5. The passage, by definite steps, of one hue, or of the tones of one hue into another related hue or its tones.

6. The passage, as in the preceding example (5), of related hues into each other, when each step is separated by a neutral element.

7. The passage, by insensible differences, of one hue into another chromatically remote hue.

8. The passage, by definite steps, of one hue into another chromatically remote hue.

9. The passage, as above (8), of one hue into another, when each step is separated by a neutral element.

10. The collocation of distant tones.

11. The collocation of chromatically distant hues with or without the interposition of neutral elements.

§ 108. It will be noticed how the idea of seriation or gradation becomes more and more involved with that of change as we follow the sequence of the above examples. Gradually the notion of orderly succession, of a regular series with the presence of a pervading and dominant constituent, is lost by the abruptness of change caused by the introduction of foreign elements, or by the contiguity of distant tones and distant hues. But if an exact classification of colour-harmonies has not as yet been realised, the colourist may rest content with the conviction that it would afford him little if any more aid in his work than what he may easily gain from the

rough and provisional schemes which have been sketched in §§ 51—54, 77—84, and 96—107. At the same time, a few instances of the mode in which chromatic harmonies may be composed or studied will serve to illustrate and enforce some of the principles which have been enunciated. Let it be remembered, however, that no rigid rules as of cast-iron should be allowed to trammel the imagination of the artist, to whom there are many things more important than rules, such as observation, knowledge, and experiment; a cultivated taste, sound judgment and a light fancy; an appreciation of what is meant by balance, distribution, and reticence of colour.

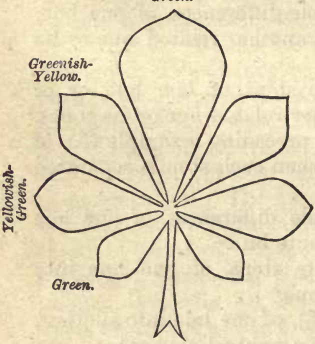

Fig. 31.

§ 109. The gradual development of the full leaf-green of spring foliage furnishes an example of gradation, not only of tones, but of hues; it conveys a notion of the gradual increase of some one quality in the series. We cannot reproduce in flat washes all the chromatic elements of the series, for the youngest leaves have a kind of veil of pale yellowish-red laid over their greenish-yellow, and this needs a kind of scumbling of one paint over another, or the apposition of many small spots of these two hues if we are to give something of its peculiar effect. But if we simplify the series of hues as far as possible, we may pass from yellow to green, through greenish-yellow and yellowish-green, and produce an example of the harmony of analogy or seriation. The four hues assumed to be present in Fig. 31 resemble in kind and in order four of the colours which in the solar spectrum lie between the yellow and the green. The

arrangement of the series conveys the idea of an increasing brightness and warmth, as we ascend from the smallest pair of leaflets close to the leaf-stalk, to the full green terminal leaflet at the summit. Fig. 32 represents the same series of colours after a diagrammatic fashion, and supplies a scientific analysis of the effects observed. The full green is represented at the base; the yellowish-green comes next with an equivalent of green, and one-third of an equivalent of red; then follows the greenish-yellow containing one equivalent of green with two-thirds of an equivalent of red; lastly we have the normal yellow, with one equivalent of each of its chromatic elements. Thus green is the chromatic member common to the whole series, which, receiving equal increments of red, passes into the normal yellow.

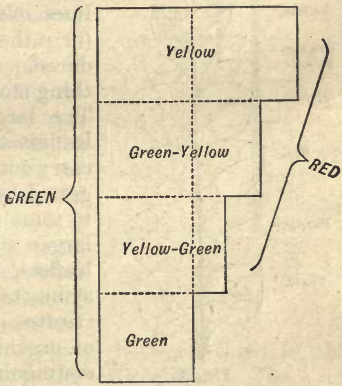

Fig. 32.

§ 110. In the next illustration (Fig. 33) the range of hues is more extensive, for it includes about 150 degrees of the chromatic circle (§ 78), instead of the 55° or 60° of Figs. 30 and 31. The series is not intended for direct use in decorative chromatic assortments, but several lessons applicable in practice may be drawn from it. The contrasts between contiguous colours in this example are more decided than in the preceding one, which was indeed an instance of the "small interval." Here we have a harmony which lies between a harmony of analogy and a harmony of contrast. It contains several hazardous associations of colours, but it is redeemed from the crudity which results from the repeated use of

awkward chromatic intervals by the one element, namely, red, which is common to the whole series, and by the gradual reduction of brightness as we descend from the luminous yellow at the summit to the deep violet at the base of the design. The analysis of the colours in Fig. 33 is represented roughly in Fig. 34, in which the thick line represents red, the medium line green and the thin line blue. Where two lines overlap a compound colour (or rather colour-sensation) is produced. But we may learn something more than this from Fig. 33. The larger development of the leaflets towards the base helps to carry out the idea of seriation suggested by the colour-sequence. If in some minor details, such as the larger size of the *second* pair of leaflets, we find a break in the symmetry of the series, this constitutes just one of those features of organic growth by which it is distinguished from the mathematically accurate but uninteresting products of mere mechanism, for very often the poetry, the mystery of beautiful organic forms, lies hid in such seeming exceptions to law.

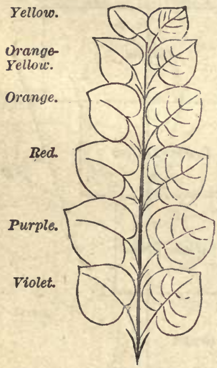

Fig. 33.

We should not fail to notice that there are several methods of more completely harmonising the adjacent hues in Figs. 31 and 33. In copying the designs in colour, for the sake of the instruction which such exercise affords, we recommend the trial of the following generally-applicable methods of bringing greater unity into such chromatic series :—

1. A fine outline and veining of black, common to all the leaflets : in Fig. 31, and in other designs where the colours are bright or pale, a deep puce, or a chocolate outline may replace the black.

2. An outline and veining of gold common to all the leaflets: a slight and partial *hatching* with gold lines often produces a good effect.

3. The addition of grey or of white to the whole of the colours used: in Fig. 31 the largest proportion should be added to the green, the least to the yellow.

§ 111. A third example of the more complex kinds of chromatic harmonies which we are now considering is shown in Fig. 35. In it two series of tones are interchanged, the tones of one hue, say of violet, *a*, *b*, *c*, and *d* in the figure, being interposed in descending order from light to dark, while the tones of the other hue, say greenish-yellow, D, C, B, and A, are placed between them in the opposite direction. The arrangement requires skilful management if it is to be employed successfully in chromatic ornament, as the juxtaposition of the similar middle tones of two hues is rarely pleasant to the eye, but it admits of frequent introduction in pictorial art. For instance, a drapery may show its deepest tones below against the lightest tones of the background, while above the circumstances may be reversed: so also a tree may have the deepest tones of its lower branches relieved against

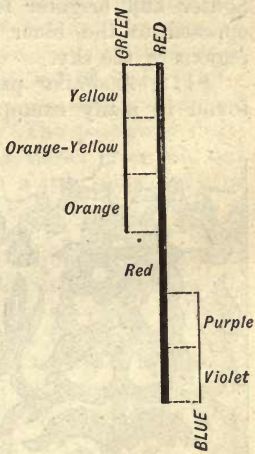

Fig. 34.

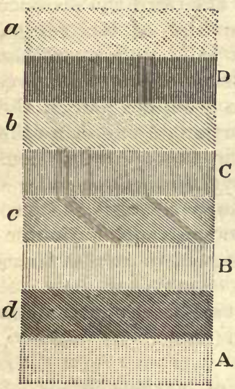

Fig. 35.

the palest tones of the sky near the horizon, while the lighter and brighter foliage towards its summit will be opposed to the bluer and deeper tones of the upper regions of the sky.

§ 112. A similar principle of *counterchange* will be found in many examples of decorative art. In the simplest colour-harmonies of this kind we have three chromatic elements only, namely, two hues, and a separating contour-line of gold. This arrangement is found in some of the embroideries and illuminated manuscripts of the later Renaissance both in Italy and Spain. Great ingenuity is often shown in managing the transition at the points where the colour of the patterned ornament becomes that of the ground, and *vice versa*. In Fig. 36 this passage is shown at about one-third the distance from the base of the design, where it will be observed that the darkened tone which represents the ground-colour in the lower portion distinguishes the pattern in the upper portion. In order that there may be a due balance between the two chief colours in such a counterchanged pattern, the total areas assigned to each of them should be nearly the same. This equality is most desirable in those cases in which the two hues differ much in brightness, as in the combination amber and crimson, or greenish-yellow and deep blue.

Fig. 36.

§ 113. To the four examples of various kinds of

chromatic arrangements, described in the preceding sections, we may now add a fifth, taken from the old faience of Damascus, Rhodes, and Fostat. In some of the most beautiful kinds of Damascus wall-tiles there occur but three colours. On a ground of pearly whiteness, conventional foliage and flowers, with arabesques, are outlined in deep cobalt blue. The patterned ornaments are filled in partly with a rather greenish, full turquoise colour, and partly with a pale bluish-grey, or lavender. Here we have an illustration of the use of the small interval, the three varieties of blue being chromatically near together, and requiring to be used with great skill, in order to form an agreeable colour-harmony. Success is achieved by adopting different tones of the three hues, and by the freedom and grace of the contours. Thus, the cobalt blue is rich and deep; the turquoise-green is of medium brightness, while the bluish-grey, or lavender, is pale. In some of the other wares of this group a beautiful clear grass-green is added to the series; in others, we have a puce, or dull purple (derived from manganese), and an olive-green. In the so-called Rhodian ware, an opaque brick-red appears, the hue of this element being somewhat variable. In some cases we meet also with a pale flesh-red, or salmon colour. A chocolate-brown, and a black, or dark grey, like that of Indian ink, complete the list. The floral forms employed were suggested by the tulip, the hyacinth, and a few other plants. The dull red of the Rhodian examples, with its yellowish tincture, balances the cool blues and green, while the Indian-ink colour, which in dishes and plates often forms a border of light circles and delicate spirals of smoke-grey, unites and tones the whole composition, and yet brightens, by contrast, the dominant series of colours. We ought not to fail to notice a most precious quality in these Oriental wares, that palpitation of colour, that absence of mechanical flatness of tint and of hardness of outline, which distinguishes the best human handiwork of the thoughtful

kind from the perfectly correct, but thoroughly insipid, work of a machine.

§ 114. Turning now to the floral world for an example of a complex colour harmony, which may serve to illustrate the effects of gradual, or of abrupt changes of hue, we choose a strange and striking plant, belonging to the mallow order (*Abutilon megapotamicum*). Here the green of the leaves offers a strong contrast with the red of the swollen calyces, and the five bright yellow petals of the corolla contrast very forcibly with the violet hue of the central group of clustered stamens—a startling assortment of colours, in which there is a double contrast, consisting of two pairs of hues, each widely separated from the other in the chromatic circle. This twofold contrast, red with green, and violet with yellow, introduces the notion of repetition, which is akin to that of seriation. But every flower which presents three distinct colours may serve to illustrate the harmony of contrast, nor need we go far for an example. Even the quiet violet, with its minute orange-hued eye, the faint green bases of the petals, and their own predominant colour, affords a colour assortment of great beauty. Similar studies of other plants should be made; it will surprise many persons to learn what a world of instruction, as well as of enjoyment, is to be found in the chromatic analysis of flowers. Forest foliage, in autumn, will afford many delightful colour-harmonies, green passing into red, and russet into flame-colour, amber, and yellow. The open landscape gives us whole series of these harmonies, and the landscape painter, apprehending the value of the gradations and contrasts which it presents, is enabled to realise the relations to each other, in tone and in hue, of the different planes of the view spread before him. In the near objects, constituting the foreground he finds an extensive range of the scales, both of tone and of colour, and the preponderance of those hues which imply the ideas of brightness and of warmth. In the middle distance the range of tones and

colours is abridged, while the far distance is commonly distinguished by retiring and cold colours, with a limited range of tone. From these, and other natural examples of gradation and contrast, we may borrow many hints, which will prove useful in applying colour to decorative purposes. Many an observant student of nature must have noticed the triple association of hues presented by an old beech-tree in early spring. The soft grey of the old bark, with the olive-green and russet-brown of the patches of moss on the trunk, present no violent contrasts, but are full of minute variations of texture, quality, and tone. A few dead leaves of yellowish-brown perchance remain, until the pale verdure of the fresh foliage conceals them from view. And, if we look a little closer, we shall doubtless see some stronger and more decided hues, some stray bit of brightness, an early flower, or gay insect, with deep hollows of shade and touches of light. Such examples as this will teach us the value of temperance in colour, and we shall mingle with our reds and yellows, with our greens and blues, abundance of those quiet colours which we cannot exactly name, but which the watchful student of nature may see trembling on the leaves of the willow, or paving the autumnal paths of the forest, or shining at eventide from the cloudy pavilions of the sun.

§ 115. The doctrine of chromatic equivalents has been mentioned in § 105, where an endeavour was made to show that it admits of very limited and very partial application. For, in considering in what proportions the several hues shall enter in this or that colour-arrangement, it should not be forgotten that we have continually to devise combinations of colour, which are not *intended to stand alone;* indeed, it is rarely possible to isolate them, even were it desirable to do so. Thus, the very elements which may be theoretically required to supply the chromatic balance to an old blue and white jar of old Chinese porcelain may be furnished by the deep brown stand on which it is placed or the panelled

background against which it is seen. We must not, then, expect in each of the fixed and movable decorations of a house that perfectly balanced proportion which the whole of them taken together may offer. The position, use, and material of each coloured object will necessitate a preponderance of certain colours, while a perfect colour-balance in each part would be likely to lead to weakness in the general effect of the whole system. But, on the other hand, the distribution of colour as to form and surface, the proportion of balance of colour, and the quality of colour are matters which no sound colourist can afford to neglect. Differences in the form occupied by one hue involve differences in its area. For an unbroken space, filled in by a single strong colour, may be intolerable, yet the same area of the same colour, broken up into small portions, through the use of a complex ornamental form, may become an element of great beauty. By distributing in some such way those powerful colours which cause the greatest retinal fatigue, we are able to employ successfully even green, violet, and red much more freely than would be deemed possible. With dulled or broken tones, whether pale or dark, no difficulty of this kind occurs, and they are constantly used with happy effect by designers who are quite unable to deal with strong primaries and secondaries.

§ 116. There is one *quality* of good colour which lies at the very root of all successful employment of vivid hues. It consists in minute variations of hue and tone within the same surface. A colour must not be absolutely uniform flat and monotonous unless it be very pale, very dull, or very dark, when the absence of this "throbbing" or "palpitating" quality, though undesirable, is less observed. We have before us, as we write, a fine old Chinese vase of turquoise crackle. Apart from the mosaic texture, resulting from the innumerable fissures in the glaze, what a number of variations in appearance does this turquoise colour offer! Where the colour is thinnest it is paler, and verges more upon green;

where it is thickest, it is at once deeper, and more blue, and there are innumerable passage hues and tones. In painting, similar effects may be produced by unequal glazings and scumblings of one hue upon another, or by apposition of minute dots and patches of closely related colours.

§ 117. One of the chief distinctions between decorative and pictorial art consists in the free use of separating contours in the former. In the completest and most advanced pictorial work the outlines are lost in a mystery of blended hues, while no large areas of a single hue unbroken by variations of tone and colour are permissible. In the pictorial treatment of extensive wall-surfaces some approach to uniformity and flatness is desirable, to secure that breadth and simplicity of effect without which the architectural unity and value of the scheme would be lost. In stained-glass windows further conventionalism is needed, for the sake both of constructional unity, and of the functions and capacity of the glass. In decorative colour-work variety in detail and in arrangement of masses must be strictly subordinated to unity of design. Frequent repetitions of the same or very similar chromatic assortments of a simple character are far more pleasing than the introduction of complex and different colour-themes. The forms in which the colours are distributed may be more or less suggested by, and may suggest natural objects, but direct imitation is inadmissible. The contour-lines which separate the colours prevent the spectator from imagining that realistic representation is intended, and, indeed, they often form from their breadth and prominent colours an important feature of the design. Pictorial works may, of course, be executed in monochrome, or with very dull or pale colours, but here, by infinite gradations of tone, light and shade are realised, and the total effect differs widely from that of a severe decorative treatment of monochrome ornament. In fine, in pictorial art, colour is a means, and not, as in decorative art, the end.

§ 118. The medium with which a pigment is mixed exercises much effect upon its tone, and even in some cases upon its hue. When a water-colour paint is wet its particles reflect (that is, scatter) less white light, and its colour becomes purer, if deeper. Oil and varnish produce the same result, but it is more pronounced, and comparatively permanent. The pallor of frescoes and of paintings of all kinds having a matt or dead surface is due to the abundance of white light which accompanies the coloured rays which they scatter. But the hue of pigments may be affected by the medium, as coloured pigments vary in this character according to the depth to which the incident light penetrates (*see* § 11). Colours are also affected by the texture of the ground on which they are laid, a rough or granular ground producing small points of light and shadow, whereby both tone and hue are modified. The same observation may be made regarding the lines of elevation and depression left by the bristles of a paint-brush. The peculiarities of surface caused by grounds and brushes, and the smooth blending of hues effected by the painting palette-knife, are more important in pictorial than in decorative colour-work, but they are liable to abuse. They should be employed to enrich and vary the tones and hues of a picture, not to mask its poverty or weakness.

CHAPTER XII.

MODIFICATION OF COLOUR BY ILLUMINATION—DIFFUSED DAYLIGHT—LIGHT OF THE SKY AND CLOUDS—SUNLIGHT—A DOMINANT COLOURED LIGHT—ARTIFICIAL LIGHTS—TWO LIGHTS.

§ 119. If we first obtain a pure bright solar spectrum, and then gradually reduce its luminosity, we shall notice these two kinds of change in the colours, namely,

a shifting in the position of the hues, and a selective reduction or even extinction of them. The red will invade the orange, so that even the line D is bordered by a sort of red-lead hue; the green will extend towards the blue-green in which the F line is now included; and the pure blue will contract. We shall then describe the spectrum as containing nothing but red, green, violet. The further stages of alteration as the brightness is still further diminished will be—

Brownish-red ...	Dull green ...	Dull violet.
Reddish-brown ...	Pale green ...	——
—— ...	Faint green ...	——

This remaining hue of faint green recalls very forcibly the peculiar colour of moonlight, the brightness of which, even when full, is but one half-millionth of that of the noonday sun. The practical application in pictorial art of these observations as to the chromatic effects of a low illumination is clearly of primary importance. The changes of hue, as well as those of tone, which are produced by variation in the intensity of the illumination are recognised by all good painters, who are well aware that, even in the absence of reflected colours from extraneous sources, the high lights, say, of a coloured drapery, differ in hue from its middle tones, and these again from its deepest. To prove this it will suffice to crush into large irregular folds a sheet of blue (artificial ultramarine) paper, when the brighter parts will show a clearer blue than the middle tints, while the deepest hollows will have a violet tinge. The mere mixture of white paint with ultramarine does not produce changes of exactly the same value as this additional illumination, while a trace of some violet colouring matter is needed to imitate the hue of the more shaded regions. In the following table are presented some of the changes of hue caused by an increase or diminution of the incident light, by which pigments and coloured objects generally are seen :—

If Light		*Increase*	*Diminish.*
Red	*becomes*	Scarlet	Purplish.
Scarlet	,,	Orange	Red.
Orange	,,	Yellow	Brown.
Yellow	,,	Paler	Olive-green.
Yellow-green	,,	Yellower	Greener.
Blue-green	,,	More blue . . .	Greener.
Artf. ultramarine	,,	Blue	More violet.
Violet	,,	More blue . . .	Purple.
Purple	,,	Redder	More violet.

§ 120. If, as we have already stated, the artist cannot precisely imitate the effect of an increased illumination by merely mixing white with his coloured pigments, so neither does the addition of black cause precisely the same amount of change in hue which is produced by diminished light. On mixing lampblack with carmine, Rood found that the mixture on the palette was more purplish in hue than the colour obtained by mixing these pigments optically by the method of rotation. The admixture of black with pigments also reduces to a marked degree their saturation or purity (freedom from white), and consequently is on the whole productive of much more complex effects than could be predicted. A curious observation, also due to Rood, relates to the admixture of black with white. It is generally allowed that even the purest black pigments, as free as possible from any tinge of colour, yield, when mixed with white pigments, a *bluish*-grey. This has been usually attributed to the fineness of the particles producing a blue colour by the same action on the light as an opalescent medium (§ 34). But it has been shown that when white and black are mingled optically on a rotating disc, the grey they yield is matched in hue (not in brightness) by a white disc into which 17 per cent. of blue, in the form of a strong wash of indigo, has been introduced. The real cause of the bluish tinge produced in these cases seems to be traceable to the fact that, with a low illumination, the nerve-fibrils of the retina which correspond to the sensation of the blue are called into action

more energetically than those which give the sensations of red and of green, and so the white we see on looking at a neutral grey is tinctured with blue.

§ 121. It has been shown in Chapter IV., that the light which reaches us from the sun is altered in hue by the more or less turbid condition of the atmosphere. It is scarcely necessary to state that the light of day varies greatly in colour. Just as a drop of milk on a sheet of black glass appears blue, so that translucent medium, the atmosphere, placed against the dark background of infinite space, shows the blue of the sky, very distinct at the zenith, but becoming gradually of a less pronounced blue tint towards the horizon. The same blue, though modified in many ways, is seen in the atmospheric layer that intervenes between the observer and distant mountains. If the sunlight be reflected from such distant mountains it will suffer the loss of part of its more refrangible rays (green, blue, and violet), and the residual transmitted beams will reach the eye tinctured with the warm hues of the less refrangible rays (yellow, orange, and red). These differences of colour often become very marked towards evening, for the sun's rays then traverse a thicker layer of the more turbid and lower region of the atmosphere and consequently become of a much warmer hue. The vast numbers of minute suspended particles in the air effect a more complete sifting out of the solar rays, so that the shaded parts of mountains and of woods then assume rich blue and blue-violet colours, due to the reflection of these constituents of the incident light, while the directly lighted parts are coloured in an opposite sense by the red, orange, and yellow rays which are transmitted. In fogs and mists, when the suspended watery particles are too large to effect this analysis of the white light of the sun, the transmitted light, though reduced in quantity, remains white, and so does the reflected light. Thus also the light reflected from dense masses of cloud is often nearly white; at other times it is grey, owing to inferior illumination; when the light

is still feebler the grey assumes a bluish or violet tinge.

The light of the sky or of clouds is reflected with very small change of hue by the smooth surface of water, such as a tranquil lake or sea. But in certain positions the observer may recognise what is called "local" colour, be it blue or green or yellow or brown of the water itself, or the colour of weeds, rocks, or sand. These local colours are produced by light which penetrates the surface of the water, and then suffers reflection. The light of the sky, as reflected from the summit of a wave, generally offers a marked contrast both of hue and tone to that which is transmitted through the water and is seen in the concavity of a wave about to break.

§ 122. We now proceed to consider the effect upon coloured objects of a light which is itself coloured—a *dominant* coloured light, as it is called. If this dominant light be strictly monochromatic, such as is furnished by an isolated beam from the solar spectrum, or by the yellow flame of burning sodium, then we should expect that those objects only which had the precise hue of the dominant light would be visible. But the quantity of white light reflected or scattered by coloured materials is often so considerable that it is rare, if not impossible, to find any substance which is absolutely incapable of reflecting some traces of all or any of its constituent rays. So a *pure* yellow light falling even upon matt or dead blue, violet, or black surfaces will be in a slight degree irregularly reflected thereupon, and so impart to them a trace of colour. It will give to each of them the appearance of a yellow of extremely low luminosity—a yellow mingled with a very large quantity of black, which, as we have learnt from § 95, is an extremely dark olive-green. But under ordinary circumstances we have not to deal, in any instance, with pure monochromatic light, but with a mixture of hues amongst which one predominates. Of such a nature is the coloured light transmitted through various kinds of coloured glass. Blue

glass, for example, permits a great part of the green, blue, and violet rays to pass, and consequently the light, which after traversing it falls upon green or violet surfaces, contains a sufficiency of green and violet rays to develop their distinctive hues to a slight extent. Chevreul, to whom we are indebted for a long series of experiments on the modification of hue experienced by coloured substances when viewed in coloured lights, obtained his results by exposing pieces of coloured cloth to diffused daylight, but illuminating half of each piece with the light passing through glasses of the several colours named. The recorded efforts are therefore partly due to the contrast between the two halves of each piece, and are true only for the special conditions of these experiments in which particular glasses, particular cloths, and a dominant, but not a pure light, were employed. The results of Chevreul, slightly modified by means of more recent experimental trials, are given in the following table:—

Red rays falling on	*White*	make it appear	*Red.*
,, ,, ,,	*Red*	,, ,,	*Deeper red.*
,, ,, ,,	*Orange*	,, ,,	*Redder.*
,, ,, ,,	*Yellow*	,, ,,	*Orange.*
,, ,, ,,	*Green*	,, ,,	*Yellowish-grey.*
,, ,, ,,	*Blue*	,, ,,	*Violet.*
,, ,, ,,	*Violet*	,, ,,	*Purple.*
,, ,, ,,	*Black*	,, ,,	*Rusty black*
Orange rays falling on	*White*	make it appear	*Orange.*
,, ,, ,,	*Red*	,, ,,	*Reddish-orange.*
,, ,, ,,	*Orange*	,, ,,	*Deeper orange.*
,, ,, ,,	*Yellow*	,, ,,	*Orange-yellow.*
,, ,, ,,	*Green*	,, ,,	*Dark yellow-green.*
,, ,, ,,	*Blue*	,, ,,	*Dark reddish-grey.*
,, ,, ,,	*Violet*	,, ,,	*Dark purplish-grey.*
,, ,, ,,	*Black*	,, ,,	*Brownish-black.*
Yellow rays falling on	*White*	make it appear	*Yellow.*
,, ,, ,,	*Red*	,, ,,	*Orange-brown.*
,, ,, ,,	*Orange*	,, ,,	*Orange-yellow.*
,, ,, ,,	*Yellow*	,, ,,	*Deeper yellow.*
,, ,, ,,	*Green*	,, ,,	*Yellowish-green.*
,, ,, ,,	*Blue*	,, ,,	*Slaty-grey.*

Yellow rays falling on	*Violet*	make it appear	*Purplish-grey.*
,, ,, ,,	*Black*	,, ,,	*Olive-black.*
Green rays falling on	*White*	make it appear	*Green.*
,, ,, ,,	*Red*	,, ,,	*Yellowish-brown.*
,, ,, ,,	*Orange*	,, ,,	*Greyish leaf-green.*
,, ,, ,,	*Yellow*	,, ,,	*Yellowish-green.*
,, ,, ,,	*Green*	,, ,,	*Deeper green.*
,, ,, ,,	*Blue*	,, ,,	*Bluish-green*
,, ,, ,,	*Violet*	,, ,,	*Bluish-grey.*
,, ,, ,,	*Black*	,, ,,	*Dark greenish-grey.*
Blue rays falling on	*White*	make it appear	*Blue.*
,, ,, ,,	*Red*	,, ,,	*Purple.*
,, ,, ,,	*Orange*	,, ,,	*Plum-brown.*
,, ,, ,,	*Yellow*	,, ,,	*Yellowish-grey.*
,, ,, ,,	*Green*	,, ,,	*Bluish-green.*
,, ,, ,,	*Blue*	,, ,,	*Deeper blue.*
,, ,, ,,	*Violet*	,, ,,	*Bluer.*
,, ,, ,,	*Black*	,, ,,	*Bluish-black.*
Violet rays falling on	*White*	make it appear	*Violet.*
,, ,, ,,	*Red*	,, ,,	*Purple.*
,, ,, ,,	*Orange*	,, ,,	*Reddish-grey.*
,, ,, ,,	*Yellow*	,, ,,	*Purplish-grey.*
,, ,, ,,	*Green*	,, ,,	*Bluish-grey.*
,, ,, ,,	*Blue*	,, ,,	*Bluish-violet.*
,, ,, ,,	*Violet*	,, ,,	*Deeper violet.*
,, ,, ,,	*Black*	,, ,,	*Violet-black.*

Although this table gives us some idea of the several directions in which certain coloured lights modify the hues of objects, it must not be forgotten that by varying the optical composition of the transmitted lights employed, or of that of the coloured objects under examination, very considerable changes of hue and tone must ensue. For, as we have already shown, a blue glass may either transmit a comparatively pure blue beam, or it may transmit a mixed beam containing much green and violet as well as blue light, yet in both cases the unaided eye will receive the sensation of blue and may be unable to perceive any difference of hue. In like manner the yellow-coloured object examined may owe its yellow colour to a group of rays of various wave-lengths, of which the combined optical sensation is yellow, or it may have a simple constitution. It is obvious that, in these

and numerous other instances, the appearances under a dominant coloured light of coloured substances can be exactly determined only by special experiments with the particular materials and under the particular conditions of illumination which prevail in each case.

§ 123. When a landscape is seen through a piece of neutral-tinted glass, the rays of different hues belonging to different regions of the spectrum, and scattered or reflected from the various objects in view, are intercepted to a nearly equal extent, and the relations of colour and of tone remain virtually unaltered. When the glass is coloured an entirely different result ensues, marked alterations of colour as well as of tone being produced.

The appearances presented may in some measure be compared with those produced by a dominant coloured light, but in many cases they are by no means the same. If we take a small piece of violet gelatine, mount it on a black card, and look at a flower garden through it, a series of effects of the following sort will be observed. Mature green foliage seen in shadow assumes a slaty-grey colour; young leaves appear of a decided grey-pink; the yellow patches on the foliage of the golden *Euonymus* and *Aucuba* are light red; the yellow tulip and the blossoms of the common gorse become a brilliant and most intense crimson-scarlet; dark-brown wallflowers have a crimson hue; a bed of white and yellow tulips contain nothing but pale lilac and bright scarlet flowers; blue, violet, and purple flowers are altered in hue to a much slighter extent. Without doubt, the extraordinary increase of diversity in tones and hues in the foliage of trees, which is brought about by the interposition of this violet film, corresponds to real differences which commonly escape observation. Particularly is this the case with the regular reflections of sky and cloud-hues from the glossy surfaces of leaves and the peculiar colours of their immature foliage. Without giving in detail the effects of other coloured media, it is perhaps worth while to

state that bright yellow flowers appear orange through a crimson medium, and greyish-yellow through a blue. A light yellow or sherry yellow film gives a glow of warmth, and *brings together* the scattered chromatic elements of an outdoor scene or landscape. Its effect is similar upon a painting, and is frequently produced by the varnish as it becomes yellow through age. But as the range of luminosity or brightness in a picture is much smaller than that of external nature, the effect of a yellow film on the colours is necessarily greater—the blue of a painted sky, for example, may be reduced to an almost neutral grey.

§ 124. In considering, as we have just done, the effects on coloured surfaces of yellow light, we have, in point of fact, considered the effects of the light of gas, of oil lamps, and of candles upon them, for all these ordinary lights are characterised by an abundance of yellow rays. This preponderance of yellow is a little less marked in the case of the light of burning paraffin and paraffin oil, which, though very far from white, is not quite so yellow as that emitted by burning stearine or tallow. When the combustion of any of the illuminants above named is made more rapid, and the heat increased, as by feeding the flames with oxygen or with previously heated air, the light becomes less yellow. The same result is secured in Welsbach's incandescent lamps, where a mantle of zirconia or other earthy oxides is intensely heated by means of a Bunsen burner. With electric glow or incandescence lamps the filament of carbon may be made to shine with a light which becomes less yellow as the strength of the current is increased; while electric arc lamps may give out even a slight excess of violet and blue rays. The light of an oil lamp or candle appears not yellow, but actually orange, by the side of an electric arc lamp, or even by the bluish light directly reflected from the sky.

§ 125. A few illustrations of the effects of the yellow illumination of objects by burning oil, gas, or candles

may now be given. Pale yellow gloves, though less bright, are hardly to be distinguished from white gloves; an orange loses some of its red and tends towards yellow. Blues, greens, violets and purples are greatly changed. The beautiful mineral known as amethyst presents by daylight, when of fine rich quality, a purple colour somewhat redder than the hue of the flower of the violet. But by night, illuminated by lamp or candle light, it loses much of its blueness and acquires so distinct a reddish hue that it might be mistaken for a carbuncle or an almandine garnet. This change is due to the relative deficiency of blue and violet rays and to the relative excess of the orange and red rays in the artificial light. A similar example of change of colour is afforded by some sapphires. The *Saphir merveilleux,* once in the Hope collection, presents a clear blue by daylight, while by candle light it appears violet. Certain flowers exhibit a still more curious property. The flowers of the viper's bugloss (*Echium vulgare*) and of the marsh forget-me-not (*Myosotis palustris*) are rose-coloured in the bud and when they begin to expand, but afterwards, when fully open, are blue. By artificial light this change of hue appears not to have taken place, at all events to any great extent, for a spray of blossoms of one of these plants seen by candle light shows its buds red or rose-coloured as before, but its fully-opened flowers are not blue but of a pale purple. The difference between red and a blue which contains some purple or violet is thus partially annulled. So also as regards blues and greens; the ordinary green pigments (aniline green and a few others excepted) are difficult to distinguish from blue pigments by candle light. Those blues which verge on green do so by their special or selective absorption of the yellow, orange, and red rays, and their reflection of the green, the blue and some of the violet. Now, as candle light is deficient in blue and violet, the green of these pigments then comes out with unusual force. But the blues which reflect a certain amount of blue and violet,

such as cobalt-blue and artificial ultramarine, become somewhat purplish and are easily distinguished from green, although they become much duller by artificial light.

§ 126. When the observations just recorded are made in a room lighted only by an artificial source of illumination, the judgment of hue is warped by the orange-yellow light which prevails. Thus, we regard white surfaces as yellow, and pale blues as grey, and unconsciously employ them as standards for comparison. By enclosing coloured objects in a camera obscura, and allowing the concentrated rays of a gas flame to fall upon them while the eye of the observer, remaining in daylight, inspects the change from above through an aperture in the camera, Rood obtained more exact results. He found that—

Carmine . . .	became	*intense and bright red.*
Blue-green . .	,,	*rather pale yellowish-green.*
Orange . . .	,,	*more brilliant orange.*
Greenish-blue . . .	,,	*rather pale greenish-yellow.*
Yellow . . .	,,	*brilliant, rather an orange-yellow.*
Blue . . .	,,	*neutral grey.*
Greenish-yellow .	,,	*yellow.*
Violet . . .	,,	*decided red-purple.*
Artificial ultramarine	,,	*violet.*

It is evident, from the results recorded in §§ 123 and 124, that the chromatic harmonies of decorative and pictorial colour will be much disturbed, and often injured when they are illuminated by the orange-yellow or yellow light of gas.

§ 127. When an object is illuminated simultaneously by two or more lights of different hues, very complex and often very beautiful phenomena of colour are produced. Some of the grandest natural chromatic effects, traceable to this double illumination, are atmospheric, and have been discussed in §§ 34 and 121. We content ourselves now with one additional illustration. When a white drapery in folds is lighted by more than

one kind of light, and is surrounded by objects of various colours, it absorbs and quenches a considerable proportion of the incident light, and scatters the rest, thus acquiring even an opalescent or iridescent variety of delicate hues and tones. An observant and sensitive artistic eye recognises and reproduces, sometimes with rather increased emphasis, these multitudinous and changeful colours like the *orient* of a fine pearl, but it is easy to miss them altogether or to exaggerate them into vulgarity.

In order to study the conditions and effects of a twofold illumination the following experiments may be made :—Place a sheet of pure white paper in such a position that it may be illuminated at once by diffused daylight and by a gaslight. Now, arrange an opaque rod vertically so that it may throw two shadows upon the paper. The shadow thrown by the daylight will be tinged with yellow, while that produced by the gas flame will be bluish, the doubly illuminated surface appearing to be nearly white. Now, as previously remarked, a gas flame emits a superabundance of yellow and orange rays, and is therefore more yellow than the light of day. In consequence of this that shadow of the rod, which is cast by diffused daylight and the boundaries of which are illuminated by the bluish daylight, appears, owing to the law of simultaneous contrast, to be yellowish. Conversely, as the light of day is bluish when compared with that of gas, that shadow of the rod which is cast by the gas flame appears bluish, being bordered by the contrasting yellowish light of the gas. Strictly speaking, the two hues are not blue and yellow, but greenish-blue and orange-yellow—two complementaries. A still more striking experiment consists in obtaining two beams of light, one of ordinary daylight and the other of daylight which has passed through a piece of red glass, and causing them to produce two shadows of the same rod. These will appear red and blue-green respectively. Similar results are met with every

day in the case of objects illuminated at the same time by natural and by artificial light. The lamps of a church may illuminate some parts of the furniture and floor with an orange-yellow light, overpowered and contrasted in other parts by the apparently purplish or violet light of day. A remarkable effect of this kind is seen when vivid sunlight illuminates a room through a window partly screened by a yellow or buff-coloured blind. Here the contrast of the two lights becomes very distinct. The light transmitted through the material in common use for blinds of this sort is of an orange-yellow hue, and it will be noticed that the direct rays escaping filtration through this medium are of the complementary violet. More complex effects of the same nature may be observed in the case of stained-glass windows. The simplest case of this kind that we can now recall is that of windows glazed with a pale greenish glass, but bordered with strips of white glass which will appear pinkish under some conditions of natural illumination. This effect is not wholly due to the proper or intrinsic colour of the daylight, but to complementary contrast between the white glass, which admits the natural rays almost unaltered, and the greenish-glass, which materially affects them.

CHAPTER XIII.

SURFACE AND STRUCTURE MODIFY COLOUR—COLOURS OF METALS—BARTON'S BUTTONS AND IRIDESCENCE—BRONZING, PATINATING, AND LACQUERING—JAPANESE ALLOYS—DAMASCENING AND PLATING—ENAMELLING ON GOLD AND SILVER.

§ 128. The colour of objects is influenced not only by the light by which they are illuminated, but also by their own peculiarities of texture, structure and surface.

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The coloured light reflected from satin is different to that of velvet, though the silk used in the manufacture of these fabrics may have been dyed in the same bath. In explaining modifications of colour produced by texture, &c., we shall select a series of illustrative examples from the mineral, vegetable and animal kingdoms. We shall then proceed to explain their colour-peculiarities, and the manner in which these may be utilised, in decorative art more particularly.

Metallic colours first claim our attention. Polished metals are distinguished by their intense power of reflecting light (silver reflects 92 per cent., white paper only 40), and by an almost complete opacity. An intense reflection of light is also observed with other than metallic surfaces, such, for instance, as the neck-feathers of the peacock and that beautiful chemical salt, the magnesium platinocyanide. But there are some points in which these lustrous colours differ from those of the true metals. We have alluded to this subject in Chapter I, and may here proceed to apply the principles of absorption and reflection of colour there laid down to the special case of metallic colours. Now, it will be allowed that, under ordinary circumstances, metals do not appear highly coloured, though their brilliancy is often intense. The angle of incidence of the light has much to do with this. When we take a polished and level plate of gold or copper and look along its surface, we shall see that it appears very brilliant, but nearly white. In such a case, the rays of light which illuminate it almost graze the surface, making an angle of nearly 180° with the reflected rays that reach the eye. But let this angle be reduced to one of a few degrees only, then the proper colour of the metal would be conspicuous. It may be still further developed and enriched by repeated reflections at a small angle of incidence. Fig. 37 illustrates the mode in which a beam of light may become in this way more highly saturated with colour by numerous reflections from two polished surfaces of

metal. From this cause, chased gold and "granulated" gold appear of a far richer colour than burnished gold. And by so shaping the grooves or lines of chasing upon any piece of coloured metal that repeated reflections at small angles of incidence occur in them, very rich colour effects may be produced. The splendid colours inside gold or gilt goblets arise from this cause. Many metals which lack distinctive colour under common conditions may thus be made to develop it. Yet the colour so produced not only changes in purity and brightness as it

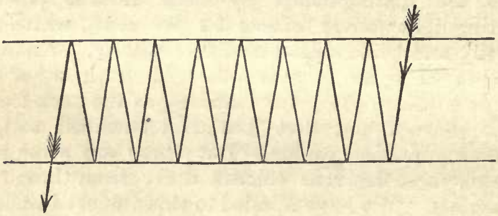

Fig. 37.

becomes enriched, but in hue it is also modified. Thus, copper may be made to yield ultimately a nearly pure or monochromatic red light by repeated reflections. The colour is more decided, it is purer; but there is less light.

The colour of a pure metal may be greatly altered by alloying it, even slightly, with another. Thus, gold twenty-two parts with two parts of silver produces a metal of a greenish-yellow colour, the greenness of which may be rendered still more decided by a small further addition of silver. Copper, on the other hand, to the extent of ten or twelve per cent., reddens gold, while a small admixture of both copper and silver does not materially affect its colour, though it makes it rather paler. A large proportion of silver, varying from twenty to fifty per cent., produces *electrum*, some specimens of which, where the silver exists in nearly equal proportion

with the gold, are almost white. Ancient and modern coins, as well as jewellery, furnish interesting examples of the variations in colour of gold produced by alloy. The old Roman gold coins with less than one per cent. of alloy show the rich characteristic orange tint of the pure metal; while in a handful of modern sovereigns the yellowish-orange ones indicate the presence in the alloy of copper and silver. The greenish ones contain silver alone, and the reddish ones copper alone. Slight as these differences of colour would appear did they belong to ordinary pigments, yet, in the case of metals, the intensity of their reflection enables us to use with effect coloured varieties of gold in ornamental jewellery. The Japanese have brought to perfection the art of employing in their beautiful lacquer a great variety of alloys of silver and copper with gold. Gold, if not alloyed very much (not more than nine parts in twenty-four) may be made to assume its proper colour by a process of "pickling" or "colouring." Gold articles, plunged when warm into nitric acid, lose a portion of their superficial alloy, be it copper or silver, the pure metal being left with a somewhat *matt*, or dead surface, and a rich orange colour; or a mixture of equal parts of borax, nitre, and sal-ammoniac may be made, ground into fine powder, mixed with a little water, and applied as a thin coating to the metal. The metallic object is then heated till a faint discoloration appears on the coating; afterwards, the paste being washed off, the pure gold film will appear beneath. With a film thus prepared, and with some of those films which are obtained by electro-metallurgical processes, the brilliancy of the metallic reflection is much impaired, though its characteristic colour may remain. This alteration arises from the loss of continuity of the metallic surface. Silver, in fact, may be so precipitated from a solution as to present a surface almost undistinguishable from a sheet of cream-wove white paper; and gold may be obtained by similar processes in a state which presents a close resemblance to

yellow ochre. Some of the most beautiful effects in the decorative employment of metals may be secured by the partial polishing or burnishing, with an agate or steel tool, of such matt or dead surfaces as these. When silver is deposited by Liebig's silvering liquid on glass, it may be made to assume a most perfect or "black" lustre, and is then applicable for use in mirrors, or in the reflectors of telescopes. Here the continuity of surface is practically perfect. Here, as in other examples of the so-called "black" polish of metals, the scattered light is reduced to the minimum and the regularly reflected light attains its maximum.

§ 129. The delicate and subtle contrast between metallic colours has led to the association of two or more metals in several kinds of decorative work. We have already referred to the varieties of coloured gold. In jewellery red gold may be used for flowers, with white gold or electrum; green gold may be employed for leaves; while the ornamental spray itself may be laid upon a chased or granulated surface of pure orange-coloured gold. By the process of parcel-gilding on silver a more decided difference of colour may be secured; while the methods of metallic inlaying and damascening enable us to obtain the more marked contrasts between iron and gold and iron and silver. In these latter cases we have not only a considerable difference of colour between the two metals, but a very distinct difference in reflecting power. Iron or steel, covered by an easy chemical process with a film of platinum, is preserved from corrosion, and still furnishes an excellent combination with silver or gold, or with both of these metals, as inlays.

Before giving a list of the colours of a few metals in their pure and unalloyed state, we may remark that other metals besides gold are remarkably modified in hue by the presence of an alloy. Perhaps copper shows this effect more commonly and more distinctly than any other metal. An alloy of 85 parts of copper with 15 parts

of tin, or with 15 parts of a mixture of tin and zinc, constitutes a mixed metal of a rich yellow colour, the pink colour of the copper being then much altered. So 5 parts of the bluish-white metal aluminium will similarly modify the colour of 95 parts of copper, an effect seen in the so-called aluminium gold, or aluminium bronze, which is thus constituted. If the copper be mixed with tin in the proportion of 70 of the former metal to 30 of the latter, then the alloy is no longer yellow, but greyish-white, forming what is known as speculum metal.

The colours of some of these metals, in a few cases ascertained and determined by two or more reflections, are here given :—

Copper . . .	Red.	Silver . . .	Orange-yellow.
Gold . . .	Orange.	Sodium . .	Rosy-pink.
Lead . . .	Bluish-grey.	Steel . . .	Neutral grey.
Mercury . .	Slate-grey.	Tin	Greyish-yellow.
Potassium .	Lavender-grey.	Zinc . . .	Bluish-white.

§ 130. There is one remarkable and important property enjoyed by metals, and particularly by gold, of at once harmonising with and setting off ordinary coloured materials. Two instances of such a use will occur to every one—the gilt frame of a picture and the gold threads in embroidery. Gold, in fact, is removed from the series of ordinary paints and dyes by the intensity of its metallic lustre, and so combines into agreeable assortments with all colours, even with those with which yellow and orange pigments do not associate well. In a picture-frame this peculiarity of its metallic lustre prevents its yellow colour from interfering with the similar hues of the picture, while its colour, being luminous and "near," gives the idea of some degree of distance to the picture itself—we seem to look through an opening upon the scene represented.

§ 131. There are many ways of modifying the colour and lustre of metallic surfaces. Grooves or shallow channels deepen the colour of metals ; very fine lines or

scratches produce in various degrees of perfection the iridescent appearance to which allusion has been made in § 32. This phenomenon of iridescence was made to originate the most exquisite arrangement of spectral colours in stellate and other patterns by the regular ruling of very fine lines upon steel. This was done by an ingenious dividing engine invented by Sir John Barton, and "Barton's Buttons" were for a time a favourite ornament. Steel may also be coloured by heating it in the air, whereby a film, producing "interference" colours, is formed upon the surface. Steel watch-springs and watch-hands owe their blue, violet, or purple hues to this film of oxide, which possesses various degrees of tenuity. On gently heating a plate of polished steel over a candle-flame, the yellow tint which first appears as a central spot becomes successively orange-brown, purple, violet, and blue, while rings of these colours, passing gradually into each other, and enlarging as the heat is raised (from 220° centigrade to 320°), surround the central hue. The Japanese workers in iron have long been acquainted with an ingenious method of coating that metal with a black film of the magnetic oxide, which forms an admirable background for their silver onlays and at the same time protects the metal from rusting. They employ the smoke of green fuel, heating the iron in the mixture of water-vapour and of tarry matters which it gives off during imperfect combustion. The numerous alloys, chiefly of copper, in the working of which the Japanese craftsmen are such consummate masters, constantly receive at their hands such treatment, in boiling chemical baths, as to develop particular colours upon the surface. Pure copper is made to acquire a translucent ruddy film of the sub-oxide; various alloys, especially those of copper with gold and antimony, and those of copper with silver and antimony, are also treated with special baths, and thereby become beautifully patinated. One of the colours thus obtained is a fine bluish or purplish-black, but by minute modifications in the constituents of the alloys and of

the "pickling" process, a great number of hues are obtained. The Japanese metal-workers go further than this, associating several alloys in various ways in the same plaque, vase, or bead. Their *moku-me*, or "wood-grain," affords an example of their skill and ingenuity in this direction, for it is made up of a series of layers of different alloys, all of different hues and all susceptible of acquiring special colours when patinated. By drilling irregularly-disced and conical depressions and by making grooves in a compound plate of this kind and then beating the vessel once more so as to produce a flat surface, the most curious wavy and variegated patternings are produced. Several methods of colouring bronze and copper have been long known in Europe. A puce hue is obtained by the use of a solution of antimonious chloride in hydrochloric acid; a steel-grey by means of platinic chloride, and various hues of brown by employing soluble alkaline sulphides. The bluish or greenish patina so often found cn antique objects of bronze consists of variable mixtures and compounds of the hydrate and carbonate of copper.

§ 132. A transparent coating of a resinous nature is frequently applied to metals of many kinds in order to enhance or modify their natural hues. In Burma and Kashmir gold is thus treated with a red varnish, which produces a rich ruddy colour. Silver, when varnished with white lac, loses something of its brilliancy, but is no longer liable to tarnish. Iron and brass may be protected from corrosion by a lacquer of which the resin known as *dragons' blood* forms an ingredient. With this preparation, silver and tin acquire a colour resembling that of gold, while iron appears like bronze. The old Dutch and Spanish "gilt" embossed and painted leathers were often richly decorated with silver leaf, so coloured with a lacquer containing gamboge as to assume the aspect of the more precious metal. Lacquers containing some of the so-called aniline or coal-tar dyes have been used of late for the decoration of metal work. The coloured

"mastics" employed as inlays in brass are applied by fusion; they melt at a very moderate temperature.

§ 133. There are four metals—gold, silver, copper, and nickel—which are employed in what are called "plating" processes. Gilding is usually applied to silver articles, and often produces a particularly happy effect when an object is "parcel-gilt." A coating of nickel, having a greyish-white hue and but little liability to corrosion, is now extensively employed for the protection and decoration of brass objects. In some instances several differently-coloured metals have been deposited electrolytically upon the same article. By judiciously associating gold, silver and copper (or nickel) in this way, some successful colour-combinations may be produced, particularly if the boundaries of the different metallic colours be emphasised by engraved outlines. The effect of these mechanical processes is, however, liable to be flat and uninteresting, and at the best they are of inferior artistic value to the older and more costly methods of inlaying and applying leaves of gold and silver. Damascening, strictly speaking, is applicable to steel only, and owes the beautiful waviness of aspect which characterises it to the presence of two or more slightly differing varieties of steel intricately blended, by welding, twisting and other mechanical operations.

§ 134. Translucent, or as they are generally termed, translucid enamels, afford a most beautiful and most permanent means for the enrichment of metallic surfaces. As in the case of coloured lacquers, the light which escapes reflection from the enamelled surface passes through the translucent film, is reflected from the metal behind, and again passes outwards, emerging strongly tinctured with colour, by its double transmission through the enamel. The enamels employed consist essentially of different kinds of glass coloured suitably with metallic oxides. Thus, blue enamels contain cobalt; puce and purple enamels are furnished by manganese, and violet enamels by a mixture of manganese and cobalt; grass-

green by chronium sesqui-oxide, and so forth. Such enamels appear on silver of their proper colour, but on gold the hue of the background produces a change of colour, sometimes advantageous, sometimes the contrary. But as the colour of gold may be greatly modified by a little alloy, it is easy to select or prepare a quality of metal suitable for each of the coloured enamels which it is desired to use. The following list includes the metals most appropriate for a few colours :—

Green.—Gold of twenty carats with four carats of silver as alloy.

Red.—Gold of twenty-two carats, with two carats of copper or of a mixed alloy.

Violet, Rose, White, Yellow.—Silver, or less suitably, white electrum.

Puce.—Electrum of sixteen carats gold, six carats silver, and two carats copper.

Orange and Brown.—Gold of twenty to twenty-two carats.

CHAPTER XIV.

COLOURS OF GLASS, EARTHENWARE, AND PORCELAIN—COLOURS OF GEMS AND MARBLES — COLOURS OF MINERAL PIGMENTS —COLOURS OF PLANTS, FLOWERS, WOODS, AND VEGETABLE FIBRES — THE COAL-TAR DYES — COLOURS OF ANIMALS AND OF ANIMAL PRODUCTS.

§ 135. The translucent enamels described in § 134 are in reality a species of glass. There is in the South Kensington Museum a beautiful Gothic cup of silver gilt, the sides and cover of which are pierced with openings in the form of windows, having the tracery filled in with clear enamel of green and blue, precisely in the way that coloured glass is employed in architecture. In India, at the present day, at Pertubghur in Rajputana, translucent or rather transparent enamels,

red, green, and blue, are introduced by fusion in pierced gold work, so that there is no metallic backing, but the enamels are seen *à jour*. Such uses as the above of translucent enamels are closely linked with the employment of coloured glass in some kinds of mosaic work and in windows. In chemical composition, as well as in physical properties, the two materials nearly approach one another. The same metallic oxides, those of iron, cobalt, chromium, copper, and manganese, are the sources of the colours in both. Both are lacking in some of those optical properties (such as pleiochroism, minute but visible intimate structure and different qualities of surface lustre) which give to natural precious stones much of their superiority over their imitations in *paste*, that is, coloured glass. In fact, glass is structureless and not crystalline. For this reason, at least in part, the most perfect and uniformly coloured glass is not by any means satisfactory or interesting from the artistic point of view. Very instructive examples of the bad effect of such glass are to be seen in many painted or coloured glass windows, especially in those which belong to the earlier period of the recent revival of Gothic art in this country. The blue, red, green, yellow, and violet glass of that time (still, alas, freely employed in the suburban staircase window, hall door, and conservatory) is deep enough in hue, but lacks real richness; it is thin and flat, though staring and crude. There is no fluctuation or vibration of colour, no breaking up and scattering of the transmitted beams of light. To accomplish this the glass must be less perfect as a mechanical product of manufacture. If the colouring material be uniformly diffused throughout the glass the glass must vary in thickness, its surfaces must be uneven; striæ, and blebs and bubbles only enhance the effect. A glass which is absolutely perfect as glass may be rightly devoted to the construction of optical instruments, but is incapable of realising the poetry of colour.

§ 136. In addition to the metallic oxides named in

the preceding section as used for imparting various colours to glass, other materials are frequently employed. For instance, there are two kinds of red glass, a common one coloured by the presence of suboxide of copper, and a rarer and more beautiful sort, in which finely divided gold imparts to the mass a splendid crimson or ruby hue. This glass in one stage of its preparation is free from colour. When this is developed it does not appear with absolute uniformity of hue and tone in every part, but with such considerable variations as to produce a very beautiful throbbing or vibrating colour. Another kind of glass owes its peculiar colour to the presence of very fine white particles, generally of tin peroxide, or of lime phosphate; these diffused through the glass give it the opalescence of a cloudy medium, so that it reflects a bluish light and transmits a yellow or orange-coloured beam. This opal glass may vary in opacity from a faint milkiness to a dense white. Avanturine glass, which seems crowded with golden spangles, contains numerous brilliant crystals of metallic copper; copper, in the form of crystals of the red suboxide, also gives its rich opaque crimson hue to the glass known as porphyrine. Canary glass, which owes its yellow colour to uranium, exhibits also a beautiful green fluorescence. A curious change, or rather development of colour, frequently occurs in white plate-glass when exposed for some time to daylight. Such glass contains manganese, which has been added in the manufacture to neutralise the greenish-yellow colour of the material. Gradually a purple hue becomes apparent, owing to a molecular or chemical change in the manganese compound present.

§ 137. The ancient glass of Egypt, Phœnicia, Greece, and Italy, is often particoloured from the interfusion and blending together of rods of various hues. Millefiori and mosaic glass are examples of this kind. The transparent colours, arranged in rosettes and set patterns, or in zigzag lines, are often mingled with opaque glass of various hues. Sometimes the patterns are relieved upon

a deep blue, an amber, or a nearly colourless ground. In the process of manufacture the regularity of the coloured designs frequently became partially obscured, either through accident or intentionally. In the latter case, when the contortion and thinning out of some of the coloured layers were pushed to the extreme limit, the irregularity of the veinings and mottlings suggests the notion of onyx, jasper, brecciated agate, or other precious natural materials. The ancient glass beads so widely scattered over the Old World are often marvels of beauty, both as regards workmanship and colour. Venice, or rather Murano, has long been famous not only for beads but for its delicate and elaborate vessels of glass. These were often decorated with affixed ornaments of various colours, or with paintings in enamels, and were sometimes partially gilt. But the cameo glass, most of which seems to have been of Roman origin, marks the highest level of artistic production in this material. In it the designs are cut in relief in a nearly opaque white glass, which forms an outer layer upon a dark, generally blue, ground. The finest extant example of this kind is the Barberini, or Portland vase, now in the British Museum. The Naples Museum contains a similar amphora decorated with vine branches and figures in white relief on a blue ground. The Chinese are also adepts in this method of treating glass made up of two or more differently coloured layers; their imitations of jade and other highly-prized minerals are also extremely ingenious. But it must be confessed that the laborious cutting of glass and the employment of it to simulate other substances is not wholly satisfactory. The properties peculiar to glass, its ductility when solidifying from a state of fusion, its beautiful surface, the variety and richness of the hues it may be made to assume, with many other precious qualities, are best seen and are susceptible of the fullest development when it is treated more naturally in the hands of the glass-blower. Enamelling and gilding, such as we find upon the beautiful Arab lamps of

mosques, are, however, a perfectly legitimate mode of decorating glass, for they serve to bring out its characteristic qualities, affording an agreeable contrast with its transparency and vitreous lustre. It should be noted that in all artistic glass, whether Venetian, Spanish, Arab, or Persian, there are many imperfections if we look at the material from a scientific standpoint. But without these imperfections not only would the colours of the glass lose those qualities on which their beauty depends, but the glass itself would no longer reveal the fact that it had been fashioned from a molten mass.

§ 138. The method of using coloured glass in windows should be limited very strictly by the nature of the material, as well as by the office of a window. The glass must not pretend to be a picture, nor must it contain large shaded or obscured portions, opaque or nearly opaque to light. Minute lines and microscopic details of drawing are out of place and worse than useless. A mosaic work of small pieces of glass is most effective. If the window be required to let in abundance of daylight, but little modified in brightness and hue, the glass may be decorated with firmly drawn outlines in dark maroon or brown, upon a silvery-white ground, the pattern extending through a large number of quarries, and being repeated several times with but slight variations of detail in each window. Here and there a medallion of richer colour may be introduced. The windows of Merton College Chapel, at Oxford, may be regarded as excellent examples of this treatment. Where highly-coloured windows are considered desirable, as in buildings in which the wall area occupied by windows is very large, then some of the richest and happiest effects are obtained by the use of blue glass in preponderating amount, as in some of the ancient glass of Canterbury Cathedral. Ruby red, with blue and a golden-yellow, yields a delightful colour-harmony, as in the windows of La Sainte Chapelle, at Paris. Some portions of the glass just named may be studied in the South Kensington Museum.

Where the pieces of glass are small, the effect of the contiguous beams of blue and violet light, when they reach the eye from some distance, is similar to that of violet glass, but infinitely richer and more full of "bloom," while the lead lines accentuate the design and prevent a too general confusion of colour. Painting in *chiaroscuro*, especially in monochrome, is radically bad in theory, and unpleasant, to say the least, in effect. Witness the glass pictures after the designs of Sir Joshua Reynolds in the ante-chapel of New College, Oxford.

§ 139. The characteristic peculiarities of the colours of earthenware and porcelain depend partly upon the body or ground and partly upon the mode in which the ceramic pigments are applied. The ground varies in hue even if no colouring matter has been artificially added; the pigments may become more or less interfused with the ground, or with the glaze, or with both, or they may remain separate from them. In the case of delft, faience, majolica and ordinary earthenware, the coloured enamels employed are painted upon an opaque white, or nearly white stanniferous enamel, or upon a whitish clay, into the substance of which they are partly absorbed. After glazing and firing, the colours are usually found to have slightly tinctured both ground and glaze, melting into them and thus effacing the hardness of the outlines. The same result ensues with underglaze painting on porcelain, where the translucency of the body sometimes adds to the softness of the chromatic effect. For the same reason opaque pigments show more distinctly and characteristically upon porcelain than upon earthenware and opaque bodies in general, as they contrast with the translucent ground. Colours, painted or printed over the glaze, are usually more sharply defined in their touches and contours than those which are laid below it. In the decoration of porcelain and pottery, besides enamel colours, gold, platinum, and silver may be used to produce particular decorative effects, while the body or the glaze may be also tinted. Some of the most remarkable

effects produced by the use of the metals named above may be seen in the various kinds of *lustred* ware. The metallic hues of this kind are due for the most part to fine films of metal reduced from their compounds in the final process of firing. The golden and ruby lustres of some of the Italian majolica of the sixteenth century, the various yellow, bronze, and copper-coloured hues of Hispano-Moorish platters, the golden and purple-bronze tints seen, often on a blue ground, on some kinds of old Persian tiles and vessels, afford beautiful examples of this species of decoration which may be studied in the ceramic collections at South Kensington. Attempts have been made during recent years to revive this curious art. Amongst the more successful of these may be named the productions of Mr. W. de Morgan, of Chelsea, who has produced many fine specimens of the different lustres due to copper, and of the *madreperla* lustre due to silver, of delicate hues of lilac, blue, pale green and yellow passing by gentle gradations into one another. An iridescent glaze, containing much bismuth, was invented by M. Brianchon, and has been imitated at Worcester and at Belleek, in Ireland.

§ 140. It ought scarcely to be necessary to vindicate for the natural precious stones a very high position amongst decorative coloured materials. Putting on one side the hardness and consequent durability of the more esteemed sorts, they present beauties and singularities of colour and optical effect which are, to a great extent, inimitable by artificial preparations. Yet, amongst a certain clique of artists and amateurs, it has become the fashion to depreciate their excellence. One distinguished critic tells us that "the colours of gems are entirely common and vulgar. The green of the emerald is the best of these, but at its best is as vulgar as house-painting, beside the green of birds' plumage, or of clear water. No diamond shows colours so pure as a dewdrop; the ruby is like the pink of an ill-dyed and half washed-out print, compared to the dianthus, and the carbuncle is not

prettier than the seed of the pomegranate." We dispute each of these assertions, for, in the diamond there is a wonderful surface-lustre, as well as greater refractive and dispersive power, and a more complete transparency than water possesses; the emerald exhibits two distinct hues in the same specimen, and there is in consequence a play of colour in this gem for which it would be idle to search in any paint; the ruby, too, exhibits a vibration of hue between purple-red and crimson-red, which gives it a charm superior to any dye. But, further, these depreciators of gems insist upon their being cut, if cut at all, in a way which is usually fatal to the development of those qualities upon which the beauty of precious stones depends. This method is known as cutting *en cabochon*, or *tallow-topped*, and is, as a rule, appropriate to those stones only which are not transparent—opals, cats' eyes, moonstones and chrysoprases. When applied to transparent gems, it prevents the full play of light and colour proper to them, internal reflection is imperfect and the marvellous dispersive power often present does not show its effect in producing the so-called "fire" of the stone. Analysed by means of a prism, the colour of gems is often found to differ from that of the nearest approach in artificial *paste*, that is, glass, that can be manufactured as an imitation of them. The minute internal fissures, to which the splendid play of colours in sphene and in the precious opal of Hungary, Mexico and Queensland is due, cannot be imitated. The opal, when polished, has its beauty enhanced by being set in a border of small brilliant cut diamonds, which form, with its soft milkiness and variegated splendour, a delicate yet effective contrast, by reason of their perfect transparency, their whiteness and their almost metallic surface lustre. The peculiarities of the "star-stones," such as the star-sapphire and the star-ruby, like those of the opal, have not been reproduced artificially. These varieties of crystallised alumina are translucent, not transparent, and owe their beauty to their intimate structure. This is properly

and fully developed only when one of these crystals is cut across its principal axis and left with its summit *en cabochon.* Then a six-rayed star makes its appearance. This star is best seen in sunlight, or by the light of a bright flame, or in the focus of a condensing lens. It is due to the symmetrically-disposed layers of which the crystal is built. The less transparent varieties of red garnet, when cut as carbuncles, occasionally show a star, but it has only four rays, owing to the simpler crystalline structure of this stone. Amongst other *chatoyant* stones having a play of light upon, or rather within them, the moonstone, a variety of one of the species of felspar, is the most familiar. Its light is more diffused than that of the asterias, or star-stone, and has a pearly sheen. Moonstones may in some cases be used to replace pearls in jewellery, and may be associated effectively with dark-coloured clear amethysts. The stones called *cats' eyes* belong to the class of chatoyant stones. There are three entirely distinct kinds, one of these, the hardest and most precious, is the chrysoberyl. It is yellow, yellowish-green, or brown, and shows a pale bluish line of light when properly cut. This effect is wholly due to the optical structure of the crystal. In one of the commoner sorts of cats' eyes there are fine parallel lines of asbestos which catch and reflect the incident light. These fibres are embedded in quartz. In the African crocidolite, or tiger-stone, which constitutes a third kind of cats' eye, we have a silicious matrix crowded with parallel fibres of a ferruginous substance; it reflects a deep golden or brown light. Bluish and reddish varieties of crocidolite also occur, and exhibit the same phenomenon.

§ 141. To one property possessed by many precious stones we have already referred when describing the two-fold hue of the emerald and the ruby. This property is called pleiochroism. A crystal which is straw yellow in one direction may be ultramarine blue in another, for a beam of white light is affected differently according to the direction in which it traverses the crystal. By

means of a small instrument called the *dichroiscope* the presence or absence of this property may be readily ascertained. But with the unassisted eye it is easily detected in many stones which are or may be used in jewellery. Amongst these we name the chrysoberyl, the green, pink, and brown tourmaline, the iolite and the amethyst; of the dichroism of the emerald and the ruby mention has already been made. There is no doubt that much of the chromatic effect of these stones is due to their dichroism. In the annexed table are given the twin-colours (as we may call them) of some of these gems, as seen in cut specimens without the aid of any optical apparatus :—

Name of Gem.	*General Colour.*	*Twin Colours.*	
Ruby	Crimson	Pure red	: Purplish-red.
Sapphire	Blue	Pure blue	: Greenish-blue.
Emerald	Green	Pure green	: Yellowish-green.
Tourmaline	Pink	Rose red	: Salmon.
,,	Leaf-green	Bluish-green	: Yellowish-green.
,,	Brown	Orange-brown	: Greenish-yellow.
Topaz	Sherry-yellow	Straw-yellow	: Pink.
Chrysoberyl	Amber	Golden brown	: Greenish-yellow.
Iolite	Lavender	Pale buff	: Violet-blue.
Amethyst	Purple	Reddish purple	: Violet-purple.

§ 142. Amongst precious stones which lack the property of pleiochroism, and which, therefore, may be termed monochroic, the garnet and the spinel may be cited as examples. Individual specimens of garnet, belonging in most cases to different varieties of the same species of this mineral, range in colour from crimson to red and amber; there are even garnets as green as the emerald. The hues exhibited by the spinel, a single well-defined mineral species, are even more varied, for they include nearly if not quite all the colours of the solar spectrum, as well as the rose pinks and purples, which cannot be obtained by the direct prismatic analysis of sunlight. Were we to attempt to describe the most beautiful combinations or associations of the above-named and of other precious stones amongst themselves,

or with gold, pearls, and enamels, we should have to do little more than repeat the suggestions as to colour-harmonies already offered in Chapters X. and XI. Yet there are two considerations not hitherto taken into account which should always influence our methods of arranging precious stones. We refer to their association according to certain qualities of *surface* and of *substance.* Stones fashioned with curved sufaces may be in general agreeably combined with those which are faceted; stones having a waxy lustre look well when grouped with those having a resinous or adamantine polish; opalescent and translucent stones harmonise pleasantly with those which are transparent. In general, it is best to avoid putting together those precious stones which have salient properties or aspects liable to come into hostile competition with each other. The annexed tabular statement of such properties presents them in a concise form and in regular sequence, and may be used in devising appropriate associations of gems. It is quoted from the author's "Handbook of Precious Stones," to which reference may be made for detailed information as to the particular kinds of gems which exhibit the several characteristics named:—

SURFACE	*Form*	1. Plane.
		2. Curved.
	Lustre	3. Metallic.
		4. Adamantine.
		5. Resinous.
		6. Vitreous.
		7. Waxy.
		8. Pearly.
		9. Silky.
SUBSTANCE	*Light*	10. Transparent.
		11. Translucent.
		12. Opalescent.
		13. Chatoyant.
		14. Opaque.
		15. Prismatic.
	Colour	16. Monochroic.
		17. Pleiochroic.
		18. Fluorescent,

§ 143. A few words may now be introduced concerning the colours of the commoner sorts of ornamental and tinted minerals, ranging from lapis-lazuli and agate down to building stones. There are two points of special importance connected with the employment of such materials. In the first place, it is very difficult and sometimes impossible to associate satisfactorily marbles and similar natural materials with tiles and the artificial products of the kiln. There is some approach to translucency in marble. With this the dull, dry, opaque surface of unglazed pottery contrasts unpleasantly, while glazed tiles are coarsely artificial in their gloss, the unevenness of which competes unsuccessfully with the level surface of polished marble. When, however, the marbles and the tiles are reduced to pieces of very small dimensions, as in the old Roman tessellated pavements, the association of natural and artificial products is quite legitimate, for the breaking up of the large areas of the materials obliterates the offensive contrast of their qualities. In some of the fine pavements at Woodchester and Cirencester in Gloucestershire the happiest effects are produced by the association of tessellæ of white, buff, grey, cream, yellow and chocolate-coloured stones, and brown Purbeck marble, with other tessellæ of yellow, red and black pottery, and even with pieces of ruby-red glass. As, however, in the case of such pavements, all the substances used received the same final polish after the laying of the pavement, the contrasts of surface are greatly mitigated. The other point for consideration in the employment of coloured marbles relates only to those which have decided mottlings and veinings of colour; these do not admit of sculptured ornament. Your surface decoration in relief will clash with nature's previous decoration in colour. The wildness and almost infinite variations of the natural tones of brown in a piece of Derbyshire alabaster are broken up and spoilt when its surface is diapered with a conventional carved ornament; the natural picturesqueness and the artificial decoration

are incongruous. The polished plane surface of a piece or slab of mottled or veined marble, or the smooth rounded contour of a shaft, displays the beauties of the material. In a carved capital, on the other hand, nature's designs in colour are disfigured by man's work in light and shade, and the sculpture is itself ruined by the casual way in which the projecting portions are here and there darkened by a rich mottling, and the recessed are brought into prominence by reason of the paleness of that part of the marble in which they are wrought. For it is inconceivable that the carver by any skill can bring his design into coincidence with the tones of the material. Examples of this incongruity between colour and form are only too common. The employment of veined Derbyshire alabaster for the interior sculptural decoration of churches was greatly favoured by the late Sir G. G. Scott. Many a costly reredos in this material illustrates the truth of the opinions we have just expressed.

§ 144. It is scarcely necessary to say that, in the most artistic times and amongst the most artistic peoples, coloured marbles and agates and lapis-lazuli have been employed, wherever available, for decorative purposes. Sometimes a shaft, sometimes a wall-panel or lining, sometimes a tessellated floor, and sometimes a tazza or a vase has been wrought out of these beautiful minerals. Where the natural markings of the marble or other substance have been distinct and rich in effect, large slabs or masses have been used; where the colour approached uniformity the material has frequently been subdivided into numerous small pieces. In some instances both methods have been employed in a single design, a large mottled and veined panel having been bordered by a rich mosaic of small tessellæ. Venetian and Saracenic art alike afford illustrations of such a combination. Examples of the Saracenic or perhaps Coptic style of mosaic will be found in the St. Maurice collection at South Kensington. In one of these, large upright slabs of richly-coloured and

veined porphyry and marble are bordered by narrow bands of marble of less distinct patterning, while these again are surrounded by strips of fine mosaic work, made up of cubes and strips, and geometrically-shaped pieces of fine marble, earthenware, glass and mother-of-pearl. From the great judgment and fine feeling for colour shown in the arrangement of these designs, and from the small size of the pieces employed, we are compelled to admit that the effect of the association of these very diverse materials is entirely satisfactory. Venetian mosaic work, in which coloured marbles and porphyries and lapis-lazuli are associated together with enamels and glass backed with gold leaf, belongs to the same category of beautiful chromatic harmonies. It is greatly to be desired that some of our native marbles and beautifully tinted building stones were more largely employed for interior decoration. If we cannot hope to rival by their means the splendour of Eastern work, or the richness of colour of the combination of red and green porphyry with yellow and white marble seen in the famous *Opus Alexandrinum*, we could easily achieve a pleasant and soft harmony of delicate hues which would agreeably vary the monotony of our favourite whitewash, or the crudity of our flat and meaningless stretches of paint.

But the whole subject of the use of natural and artificial colour in architecture and sculpture is fraught with difficulty. We cannot, however, go far wrong if we interfere as little as possible with the picturesqueness of nature's chromatic arrangements whenever they possess a distinctive character : with uncoloured and less interesting marbles and stones, the case is certainly different. With pure white marble, having a slight translucency and a beautiful sub-crystalline texture, it often seems better not to interfere by any additions of artificial colouring. The substance appears so thoroughly fitted for the presentation of ideal forms that even the barest suggestion of realistic colour may look like sacrilege, and may easily lapse into vulgarity. This degradation is

more particularly liable to occur when the sculpture is placed near the level of the eye and in a good but not very strong light. And here a curious effect of very powerful illumination and of a dim light may be noted. Strongly coloured surfaces are rendered pallid by brilliant sunshine, a clear atmosphere and a deep blue sky, reflecting, under such circumstances, an augmented proportion of white light. And when the light is dim, as in the interior of many an Eastern dwelling, the most decided colours lose their staring and obtrusive character, and merge into a harmony of darkened tones. In England we generally have to deal with the effects of a moderate degree of illumination, and in consequence we cannot reckon upon any considerable modification of the decided colours we may employ. In architectural interiors, where poor-looking or inferior materials (whether wood or stone) are employed, widely divergent opinions have been urged as to the mode in which artificial colour should be distributed. If the lines, contours, mouldings and carvings are good, it is argued that they do not need accentuation with colour: if they are weak and poor, colour will but bring out their defects. And a scheme of artificial colouring, if quite independent of architectural forms, has the great drawback of breaking up the structural unity of the work. On the whole it may be concluded that the only safe course is to arrange and calculate beforehand the scheme of form and colour as a united whole.

§ 145. A very important series of pigments is furnished, either directly or indirectly, by minerals. Many of these products are permanent. The compounds of iron, mainly the peroxide and its combinations with water, have always been used extensively in the arts, and supply a great variety of useful colours—yellows, reds, maroons, and browns. The colours derived from copper —such as chessylite or blue verditer, or blue bice, and malachite or green verditer—are liable to change in hue, and sometimes become dark brown from the formation of

copper sulphide. The true ultramarine obtained from lapis-lazuli is a superb blue and practically permanent; the artificial variety, even when properly prepared, is somewhat sensitive to acids and alum. White lead and chrome-yellow are liable to blacken, even when protected by oil, but may be rendered less prone to change if associated with copal varnish. It will be noted from the above-named examples of pigments of inorganic origin that they vary much in one of their most important qualities, that of permanence. But that question requires a treatise for adequate discussion; and it is further complicated by considerations touching the painting-medium employed and the commixture of pigments with one another. We may, however, with advantage give a selected list of those pigments which are generally available for use in decorative and pictorial art, and which may serve in some measure to represent some of the hues to which attention has been called in the earlier chapters of the present volume. It may be premised that vermilion, emerald green and flake-white should be excluded from water-colour work, but are admissible in oil-painting. In order to avoid a supplementary list we have introduced, where necessary, two or three pigments of organic origin, which do not properly belong to the present section.

Red.—Vermilion: Indian, Venetian and light red: preparations of madder. A slight wash of madder-red over vermilion nearly represents the typical spectral red; the chocolate colour seen at the least-refracted end of the solar spectrum may be represented by a mixture of vermilion and lamp-black.

Orange.—Cadmium red serves as a connecting link between the red and the orange of the spectrum: cadmium orange and cadmium yellow come next in order: mixed with black or black and zinc white these pigments yield various hues and tints of buff, fawn, and yellow-brown.

Yellow.—Lemon yellow makes a fair approach to the

normal yellow. Aureolin is nearly transparent in thin washes : mixed with black it gives peculiar hues of olive-green, sometimes called *dark* yellow.

Green.—Emerald green, with a trace of lemon yellow, may be taken to represent the normal green. Viridian has a bluer hue and is very nearly transparent. The best kinds of vert de cobalt afford hues which may be called blue-green.

Blue.—True ultramarine is not far from a pure and normal blue. Artificial ultramarine is generally of a rather violet cast, but has been obtained of a greenish and also of a decided violet colour. Prussian blue is transparent, of great saturation, but has a decided tincture of green in it.

Violet and Purple.—No permanent pigments exist having saturated and pure violet and purple colours. Approximations to these hues may be obtained by glazing genuine ultramarine with more or less madder carmine.

Dulled or Broken Colours.—Yellow ochre, raw siena, burnt siena, and many other preparations of iron, natural or artificial, may be employed to represent broken hues. Many of them may also be obtained by mixing two distinct and rich pigments together, or by the addition of lamp-black, or of lamp-black and zinc white to them.

With the aid of the above-named pigments nearly all the illustrative examples of colours and colour-combinations named in the present volume may be prepared. For purples and violets recourse may be had to Hofmann's violet, to mauve, to magenta, and to many other coal-tar dyes. But none of these colouring matters are sufficiently stable for any purpose where permanency is requisite.

It may here be remarked that while the specific optical qualities of different pigments depend mainly upon their selective absorptive power for rays of different refrangibilities, there is another most important characteristic which influences, to a greater degree than at first sight might be imagined, the nature of their chromatic

effect. This consists in the varying degrees of translucency and opacity which they possess. Thus a transparent pigment may be much less saturated or intense than an opaque one of the same hue, and yet may produce an equal colour-effect. For the light reflected from a transparent colour has passed *twice* through it, and is more free from white light than the light scattered by an opaque pigment. Then, again, the thickness of the layer of an opaque pigment has less influence upon its hue (apart from its tone) than in the case of a transparent pigment. The application of transparent pigments upon opaque grounds, or painted surfaces, is called *glazing* by artists, and gives a richness and vibration of hue which cannot be obtained in other ways. *Scumbling* is the converse of glazing, for in it a thin film of an opaque colour, or of white, is used to cover partially, and thus to modify, the colours which have been previously laid on. It conveys an idea of distance, of atmosphere or of mystery. By ingenious combinations of glazings and scumblings, the peculiarities of texture and surface in such materials as marble, fur and feathers may be imitated.

§ 146. Amongst colours of vegetable origin, those of leaves and flowers first claim attention. The special colouring matter, called chlorophyll, or leaf-green, on which the general hue of foliage depends, has peculiar optical properties, already mentioned in §§ 28 and 37. Both in the solid state and in solution, it shows a red fluorescence; while a thin layer of its solution, in ether or alcohol, transmits green light, and a thick layer, dark red. Thus it is obvious that the yellowish-green light of various tones and hues reflected by and transmitted by green leaves is of a very complex character. In fact, ordinary foliage, when illuminated by the reddish light of sunset, puts on an orange-red hue because of the power possessed by chlorophyll of reflecting the extreme red of the spectrum, as well as of its yellow and greenish-yellow; these combined produce an orange-red. A spray

of green foliage laid upon a piece of paper painted with a pigment exactly matching its hue shows the peculiarity of the light which it reflects when it is illuminated by a red light, or when it is viewed through a combination of a deep cobalt blue and a deep yellow glass; the foliage appears red on a black ground. But the chromatic appearances of leaves are not wholly due to the presence of chlorophyll. There are also present in them other colouring matters, such as erythrophyll, a beautiful crimson colouring matter. To this substance, which abounds in the leaves and stems of that beautiful plant and its many varieties, the *Coleus Verschaffeltii*, and in the copper-beech, the colours of many flowers and fruits (such as purple grapes) are in great measure due. It also goes under the names of colein and œnolin, but though generally diffused in the vegetable kingdom is not the only red colouring matter present in plants. It is very sensitive to the presence of alkaline and acid substances, becoming blue, violet, or even green by the action of the former and a purer red by the action of the latter. It is almost certain that to these changes of hue of erythrophyll are due many of the varied hues of red, crimson, purple, violet, and even blue flowers. But some at least of the peculiar beauties of floral colours depend upon the structure of the cells within which the vegetable pigments occur. These cells are bounded by walls, often very thin and presenting a soft, glistening aspect, which enhances and varies the colour-effects of their contents. This aspect, though often called crystalline, in no degree arises from any structure to which this term is applicable. Some very beautiful and comparatively permanent colouring matters are derived from plants, but these, as a general rule, do not exist ready-formed. As instances in point, we may cite indigo, and the alizarin and purpurin of the madder-root.

§ 147. The colours of woods are usually subdued, but varied. Some of the more richly coloured species contain dye-stuffs which are liable to fade on exposure to

light; the paler kinds, on the contrary, generally deepen in tint after a time. But much of the beauty of wood depends upon texture and lustre, rather than upon very definite colour. The medullary rays which give the so-called silver grain, the annual rings of growth, and the undulations of the fibres, all combine to enhance the beauty of colour in wood. In furniture and the general decorative treatment of wooden construction, much use may be made of the contrasts afforded by peculiarities of texture as well as of colour. One wood, dark in colour, but of lustrous texture, may be introduced in the form of bosses, panels, mouldings and inlays into a framework of an opaque and light wood. So woods having distinct mottlings and figurings may be happily associated with those which exhibit a more uniform appearance. The colours and grain of woods are often brought out by varnishing and oiling, but these processes have a tendency to check those alterations of hue and tone which often render old specimens of wood-work far more agreeable than new. The fibres of vegetable origin used in the manufacture of textile fabrics are generally nearly white or very pale brown, but they may be dyed or stained of any colour. Usually, colouring matters can be made to adhere permanently to vegetable fibres only by means of a mordant. First of all, a substance such as tin peroxide or alumina, having itself an attraction for colouring matter, is precipitated upon the fibre, and then it is immersed in a dye-bath. The colouring matter is withdrawn from the liquid and becomes fixed firmly to the mordanted fibre. The lustre of vegetable fibres is usually not strongly developed and is diminished in the operations of bleaching and dyeing. Linen, the woven fibres of flax, does, however, reflect—particularly in some positions—much of the light which falls upon it. A pattern may thus be made in which the strands forming the warp contrast in lustre, even when no colour has been added, with the strands of the woof. Under these conditions damasked linen, like silk damask, may

exhibit a curious optical illusion. If a white warp and a red woof be combined, it will be noticed that in certain positions the white parts of the fabric assume a bluish-green tint, acquiring, very distinctly, the hue complementary to that of the dyed threads, the effect being enhanced by the difference of lustre dependent upon the way in which the light falls upon the fabric. Similar but more marked effects are seen in fabrics where lustrous silk and dull cotton or wool are associated. And we may here mention the peculiar mingled hues which are produced by the repeated recurrence, at very small intervals, of similarly coloured strands, in a fabric consisting of two or more colours.

§ 148. Under the name of coal-tar dyes an immense number of colouring matters derived indirectly from coal, a vegetable product, have been introduced as dyeing materials. The hues they possess are, for the most part, highly saturated; they range in colour from the fullest red through every hue of orange, yellow, green, blue, violet and purple. The extreme brightness and saturation which these colours generally possess render them difficult of management in chromatic combinations. But by considerable subdivision of the spaces they occupy, by the association with them of abundance of paler tints and dulled tones, and by the occasional reduction of their transparency by the addition of solid white and other opaque pigments, it is possible to use these telling and conspicuous dye-stuffs with satisfactory effects. Many of them are of peculiar interest from a scientific standpoint. Amongst them are three colouring matters which do not merely resemble, but are actually identical with, certain pigments previously known only as obtained directly from plants. We refer to the alizarin and purpurin of the madder-root, and to indigo. It is also interesting to find that chemists are able, in some cases, to predict what change of hue will be brought about by effecting in a colouring substance of this type what is called a *replacement*. Thus by introducing one, two

or three *methyl-groups* into the red dye known as magenta its hue becomes more and more modified in the direction of blue, passing through a purple and a violet stage.

§ 149. The colours which adorn animals are distributed in a very strange and apparently capricious way, and, in many cases, show no correspondence with the structure of their bodies. These colours arise in great part from the minute sculpturing, reticulation and scoring of the surface, and not from definite colouring matters like those present in plants. The metallic colours of the humming-bird and the peacock must be attributed in the main to what may be called the optical structure of the web of the feathers: they are, in fact, *interference* colours (*see* §.30) relieved against a dark background, which owes its blackness to a black or dark brown pigment. Instances, however, do occur in which an actual pigment or colouring matter exists in, and may be extracted from, coloured feathers. Thus amongst the Touracos or plantain eaters of Africa there are no less than eleven species which owe their splendid crimson coloration to a definite pigment discovered by the present writer. This pigment is remarkable in many ways, notably in containing as an essential ingredient no less than 8 per cent. of metallic copper. And from other birds several other colouring matters, soluble in alcohol or in soda solution have been extracted. As a rule, these pigments are much more permanent than those of flowers.

§ 150. All animal substances, including leather, vellum, silk, wool and feathers, and even ivory and bone, may be dyed without the intervention of a mordant, for they possess a natural attraction for colouring matters. As in the case of vegetable tissues, animal fibres differ much in lustre, silk greatly excelling wool in this respect. Thus the coloured light reflected from dyed silk is more saturated or purer than that from dyed wool. There is also more play of light and shade, and even of hue, in

silk fabrics than in those of wool, for the fibres of silk can be made to assume parallel positions and to lie in compact bundles, and thus are enabled to regularly reflect much white light in some places, and very richly coloured light in others. Woollen fabrics, on the other hand, appear comparatively dead, for the irregularity of their fibres and their low degree of lustre preclude them from producing the same *sheen* as that of silk. The contrast between the chromatic appearance of the two fibres is well seen and effectively utilised in mixed fabrics where the warp is of one of these materials and the woof of the other; or the ground may be of wool, and the pattern of silk. But in silk itself the range of lustre is so great, according to the mode of working it up, that strong contrasts of light and shade may be obtained in fabrics of this fibre unmixed. Very beautiful monochrome designs have been executed in cut velvet upon a glistening silk ground, the velvet pile reflecting very little white light, and the satin or silk ground a great deal

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